JANSKY & BAILEY ENGINEERING DEPARTMENT

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TROPICAL PROPAGATION RESEARCH

Semiannual Report Number 8

1 July 1966 - 31 December 1966

Prepared for

U.S. ARMY ELECTRONICS COMMAND

Fort Monmouth, New Jersey

Signal Corps Contract

DA 36-039 SC 90889

Sponsored by

ADVANCED RESEARCH PROJECTS AGENCY

Office of Secretary of Defense

ARPA ORDER 371

ATLANTIC RESEARCH

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Engineering Department
of
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Alexandria, Virginia

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Approved by

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ABSTRACT

This is Semiannual Report Number 8 on a research program involving studies of the propagation of radio waves in a tropically vegetated environment. It represents the first report of activities in an area located about 40 miles from the coastal town of Songkhla in southern Thailand. A primary objective of this work is to supplement and also provide a comparison with the results, described in previous reports, of the extensive experimental and theoretical program near Pak Chong, Thailand. Songkhla is classified as a rainy tropical region and is characterized as having a 50 per cent heavier rainfall and much denser and taller vegetation than Pak Chong, which is classified as a wet-dry tropical region. Contained in the report are descriptions of the environment in the test area and of the test facilities that have been established. The experimental goals and test procedures are set forth covering such topics as the effects upon transmission loss of frequency, antenna heights, polarization, and transmission range. Some preliminary results of measurements, based on all the data obtained from Songkhla as of 31 December 1966, are given in the form of 15 plots of basic transmission loss as a function of distance for various frequencies, transmitting antenna heights, and paths. The receiving antennas are fixed at a height of 6 feet, and the polarization is horizontal. Much of the instrumentation used at Songkhla is the same as that used at Pak Chong. Several changes, however, were necessary and are described in this report.

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1. INTRODUCTION

This report, Semiannual Report Number 8, describes the activities of the Jansky & Bailey Engineering Department of Atlantic Research Corporation in conducting theoretical and experimental studies of radio propagation in a tropically vegetated environment in southern Thailand.

The program is sponsored by the Advanced Research Projects Agency of the Department of Defense as part of SEACORE and is under the technical and contractual direction of the U. S. Army Electronics Command, Fort Monmouth, New Jersey.

Previous reports have been concerned with the results of an extensive measurement program in Pak Chong, Thailand, an area classified as a wet-dry tropical region. In Pak Chong radio propagation data as well as data on the physical aspects of the environment was collected. Among other things, the data has been used in the development of models and methods for range performance predictions. One important goal of this program is to develop these models to the point where they are capable of useful predictions in different types of tropically vegetated regions. This requires that data be collected from other environments whose characteristics differ from those at Pak Chong. To gather special data about the propagation of high frequency signals (550 Mc/s to 10 Gc/s) through bamboo growth, a short series of tests was conducted at Sattahip, Thailand, in 1965, concurrently with the tests going on at Pak Chong, Thailand. However, it was also planned to initiate a second series of tests in significantly denser jungle vegetation, following the end of the Pak Chong tests. A site near Songkhla, Thailand, was chosen after surveys conducted by MRDC, USAECOM, and J&B showed this area to have the desired climate and vegetation. Songkhla is classified as a rainy tropical region, its rainfall is 50 per cent greater than at Pak Chong, and its vegetation is much denser and taller.

Based on the environmental information presently available, a more detailed description of the climate, terrain, and vegetation at Songkhla is presented in Section 2. Also described in Section 2 is the support system for the test program.

Section 3 outlines the theory and procedures behind the different propagation tests that have been and will be conducted at Songkhla. This section explains the means by which the effects on radio propagation of vegetation, weather, transmission, distance frequency, polarization, and antenna height will be determined.

Since the period of activity covered by this report has been primarily devoted to constructing new test facilities and putting the Songkhla test program into operation, there was not time enough to gather any complete sets of data. Therefore, the portion of this report concerned with data, Section 4, simply presents the data received during this report period and explains how the data was obtained and what it represents. Until a more complete set of measurements is received, the data will not be analyzed.

Section 5 reviews the instrumentation in use at Songkhla and explains the special modifications on equipment from Pak Chong which were necessitated by the different procedures and environment at Songkhla.

2. TEST AREA DESCRIPTION

This section of the report describes the location and environment of the region in which the Songkhla propagation tests are being conducted. Also described here are the facilities and logistical arrangements for this test series, since to a large extent they were determined by the environmental characteristics of the test area.

The Pak Chong propagation tests, which ended in June 1966, showed how radio propagation is affected by medium heavy tropical vegetation. To obtain additional data that would most contribute to the ability to predict radio wave behavior in all varieties of tropical vegetation, a second series of tests was planned for an area having significantly thicker jungle vegetation. To eliminate the effects of rough terrain, it was hoped to locate a relatively level area. Since interest was focused on short-range effects, the area did not need to be as large as the Pak Chong area.

A forestry consultant was contracted to aid in finding a new area. The report of his survey conducted in Thailand to locate an area having the required attributes is in Appendix A of Semiannual Report Number 7. Nine different areas were investigated. Of them, eight were considered unsatisfactory due to inadequate size, too little vegetation, or too rough terrain. The one satisfactory area found was on the southern peninsula of Thailand. Officially, this test location is called Area II to relate it to Area I, which was the title for the test site near Pak Chong. However, Area II is commonly called the Songkhla test area, a name derived from the coastal town of Songkhla where the field personnel are quartered.

2.1 Test Area Environment

The section of thick rain forest being used for the radio propagation tests is located at 7°00' N latitude and 99°55' E longitude. A map of Thailand in Figure 2.1 shows that the Songkhla area is much further south than either the Pak Chong or Sattahip areas. It is also much more distant from Bangkok than either of the other areas, being approximately 525 air miles from Bangkok, whereas Pak Chong is 100 miles distant, and Sattahip is 80 miles distant.

2.1.1 Terrain

As mentioned earlier, one of the purposes of the site survey was to locate an area with fairly level terrain. This condition makes it easier to accurately identify and separate the effects of foliage upon radio propagation. Where uneven terrain and thick foliage are found together, it is often impossible to determine how much each contributes to the path loss of a signal. The general appearance of the Songkhla test area can be seen in Figure 2.2, which is an aerial view of the jungle covered terrain around the base site.

The four graphs shown in Figure 2.3 are the terrain profiles of the four measurement trails which have so far been completed at the Songkhla site. Although the terrain has numerous dips and hills, giving it about a ±50-foot variation in elevation, the 100 to 150-foot high jungle has a far greater effect on short-range radio signals than do these small undulations of the terrain and in most cases blankets the effects of terrain variations. As a comparison,

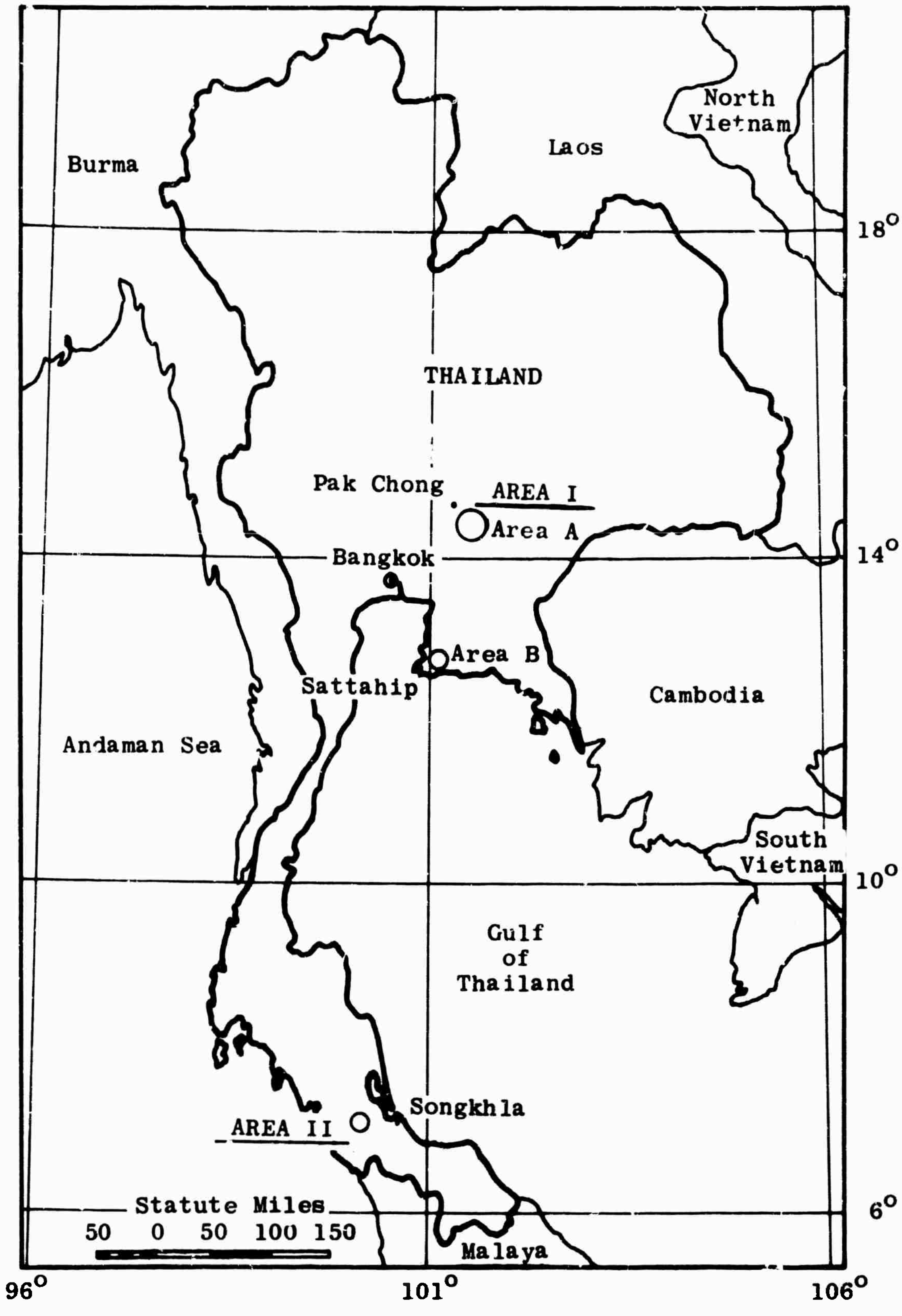


Figure 2.1 Locations of Thailand Test Areas

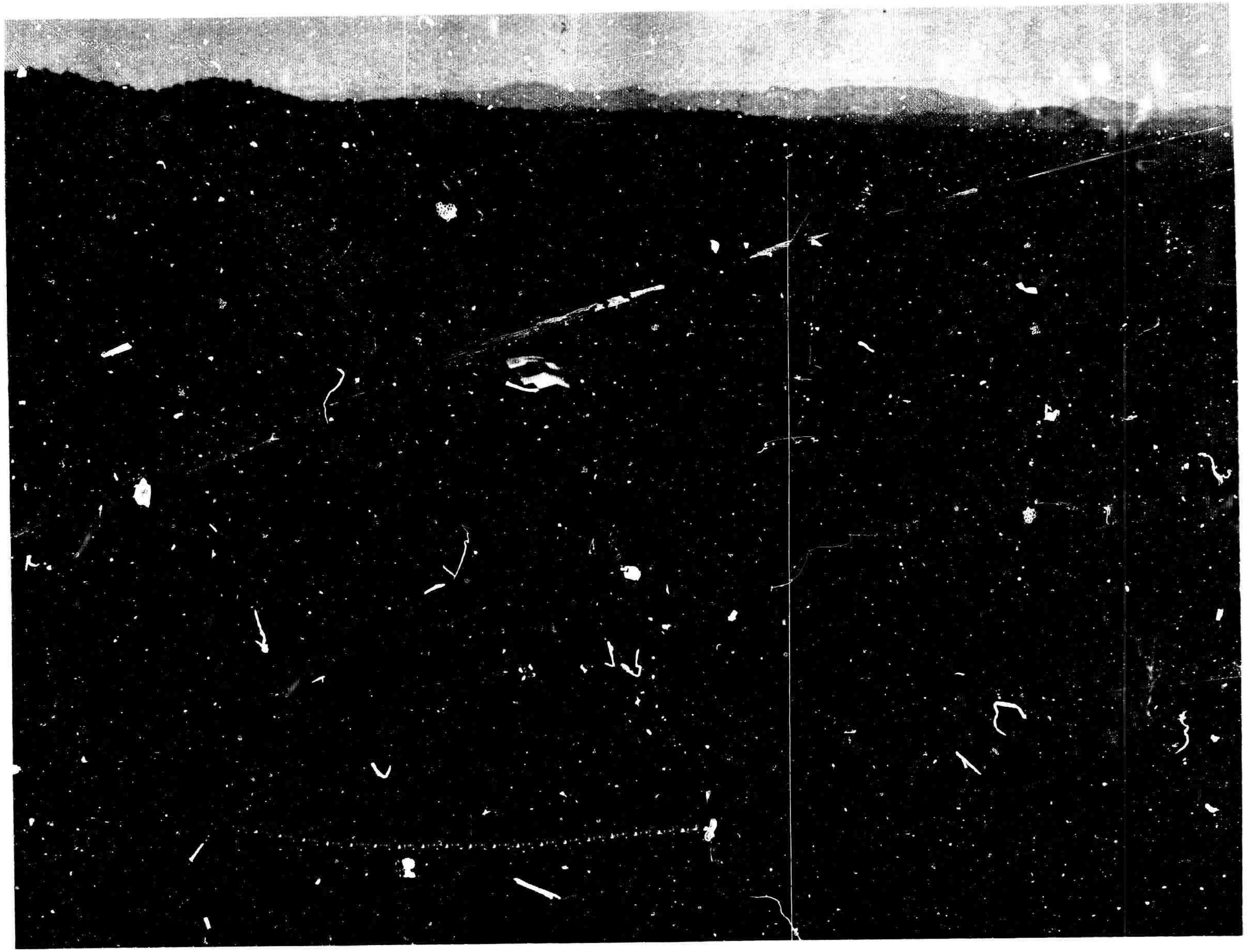


Figure 2.2 Aerial View of Songkhla (Area II) Test Terrain

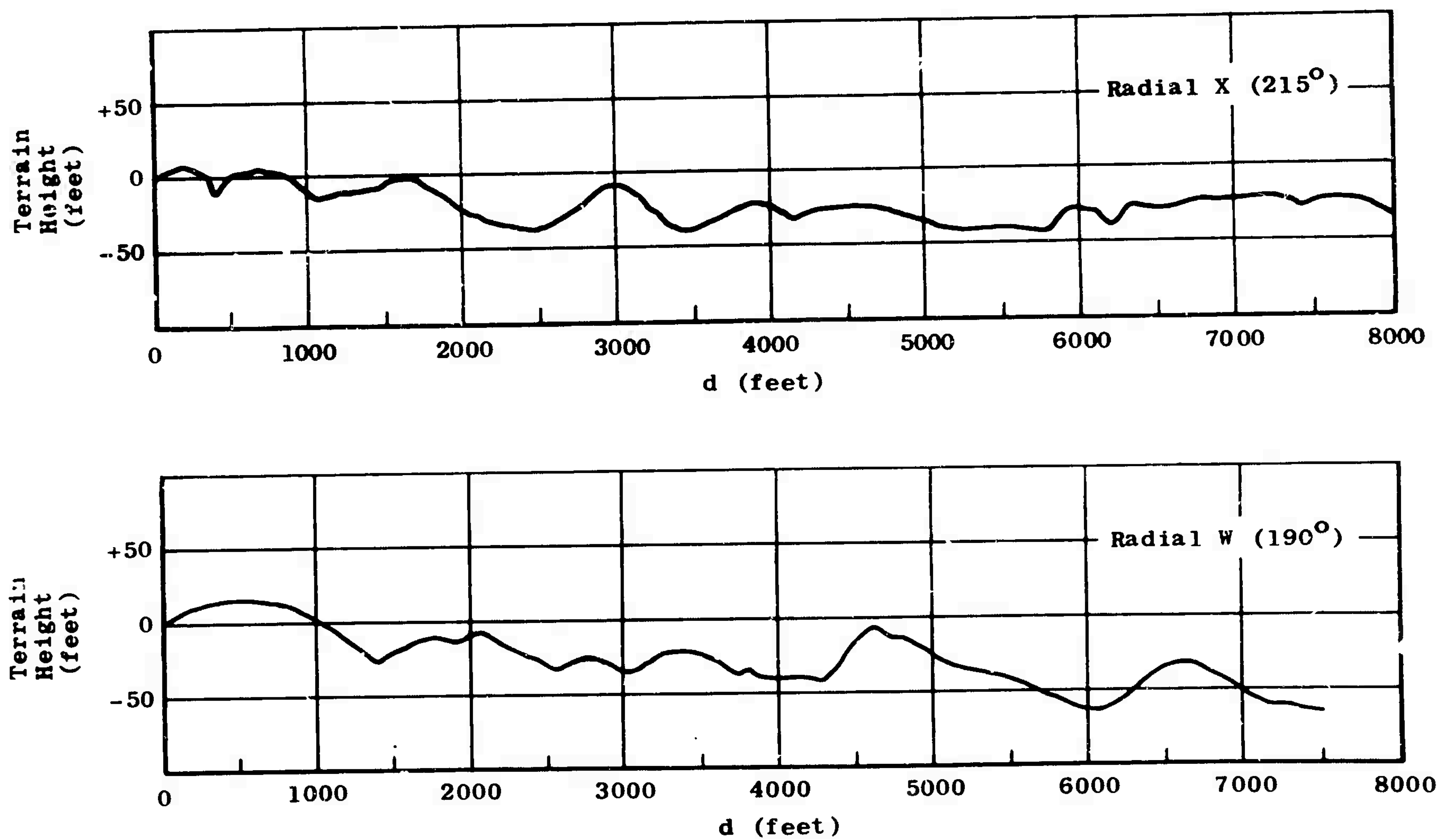


Figure 2.3a Terrain Profiles for Songkhla Radials X and W

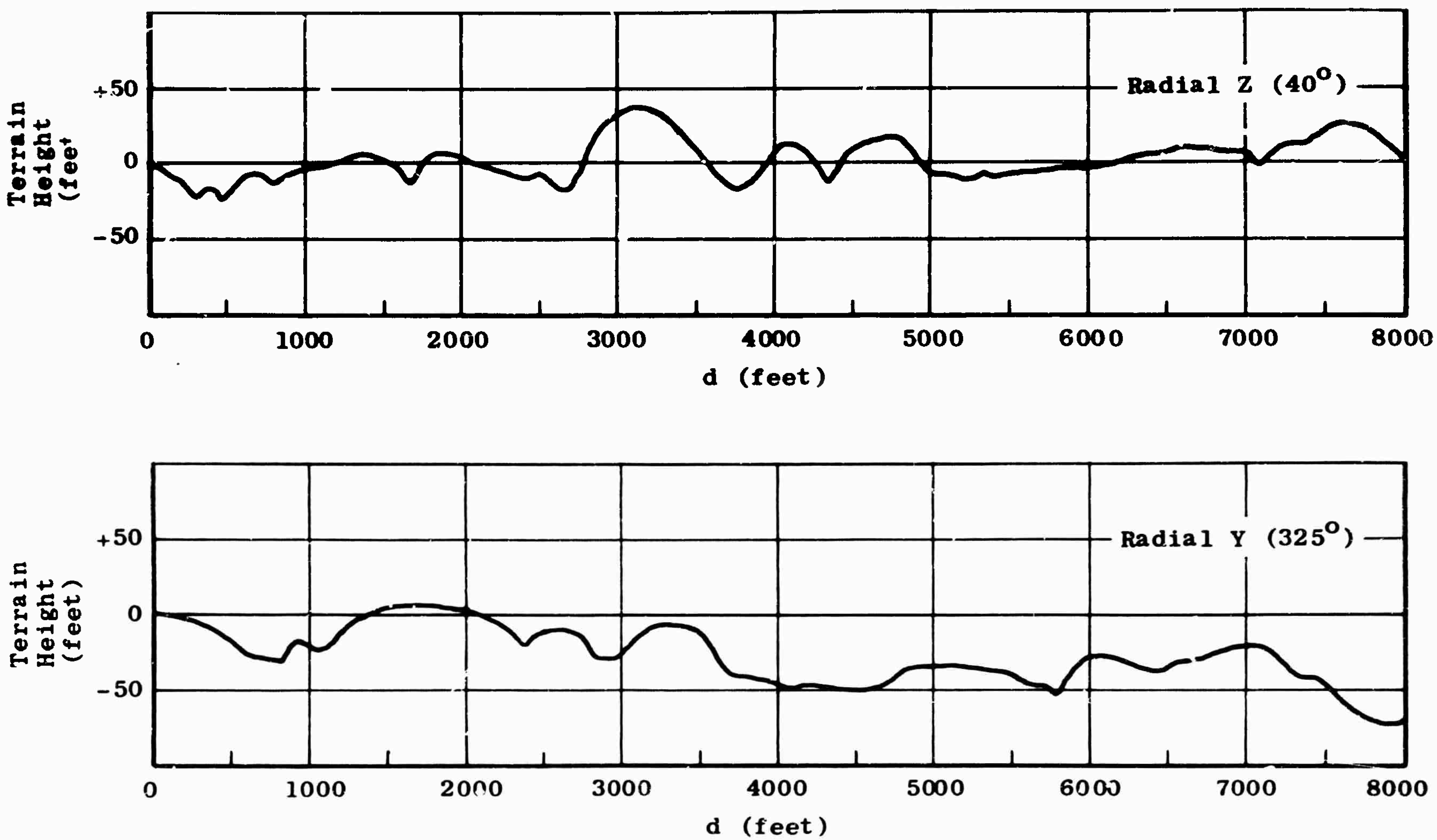


Figure 2.3b Terrain Profiles for Songkhla Radials Z and Y

Figure 2.4 illustrates the terrain found in the Pak Chong test area. The less detailed terrain profiles from Pak Chong are the result of the measurements having been made with a precision altimeter rather than the transit used at Songkhla.

2.1.2 Climate

A significant feature of the region around Songkhla is that it receives precipitation from both the northeast and northwest monsoon rains in Thailand. Because of this, the rainfall there is about the heaviest anywhere in Thailand. Annual rainfall is around 95 inches. This total is about 50 per cent higher than the yearly total for Pak Chong, which has 60-65 inches of rain annually.

Figure 2.5 compares the monthly rainfall for the two test areas. The monthly trends indicate that Pak Chong has heavy rainfall during the summer and normal rainfall in the other seasons. At Songkhla rainfall steadily increases from a low level at the beginning of the year until November when it falls off for about two months. It would seem that the heavier and higher jungle at Songkhla is principally a result of the higher rainfall and humidity in that area, since the temperatures of the two test areas are not significantly different. At Pak Chong average daily temperatures ranged from 70-80° F, and at Songkhla they vary between 75 and 85° F.

2.1.3 Vegetation

A discussion of the plant life at the Songkhla test site can be found in the Site Survey Report in Appendix A of

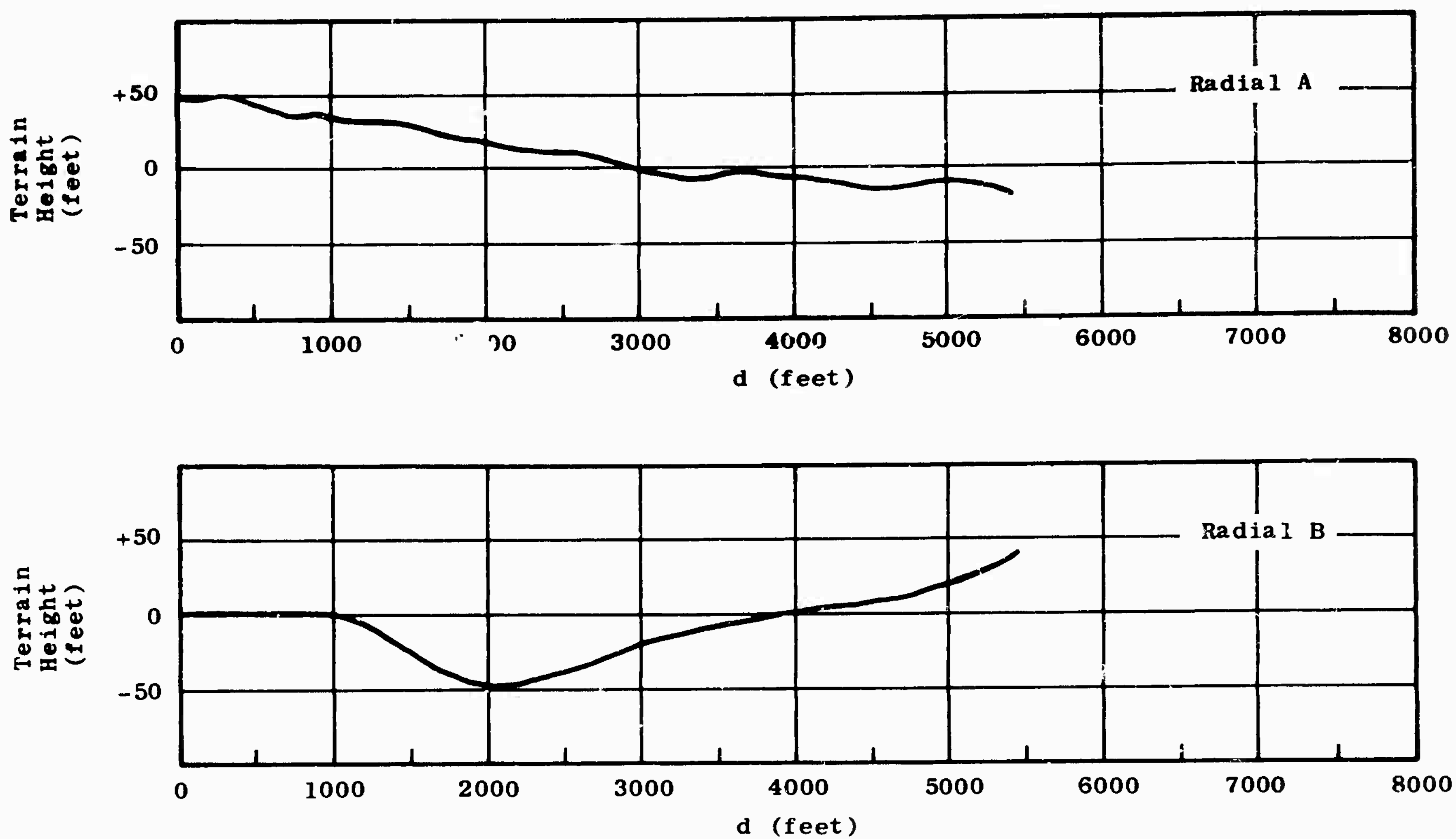
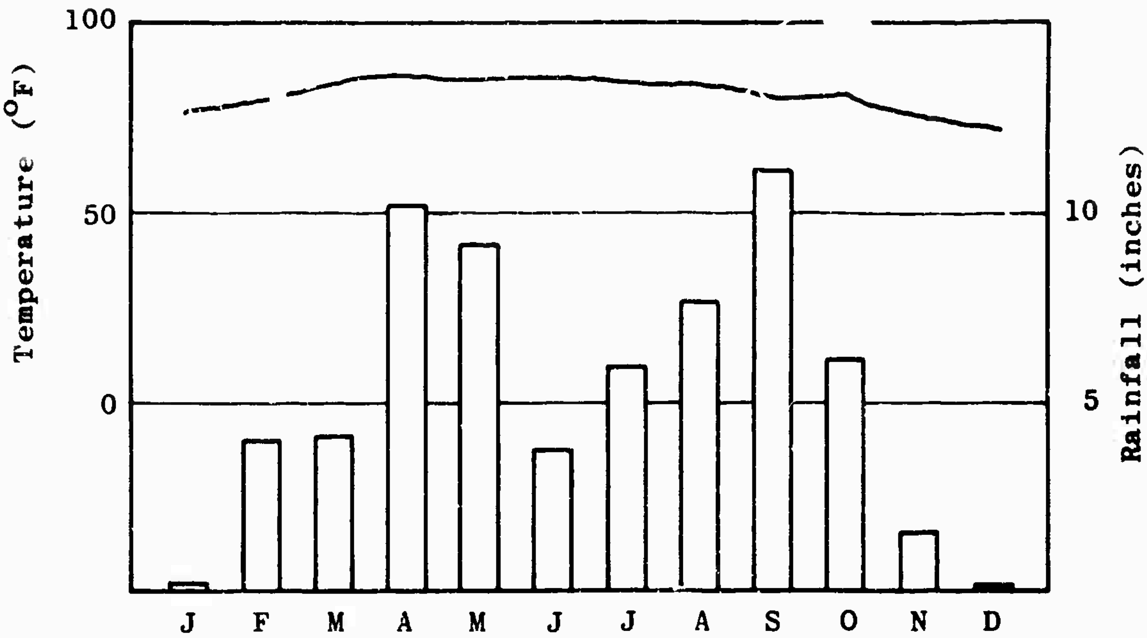
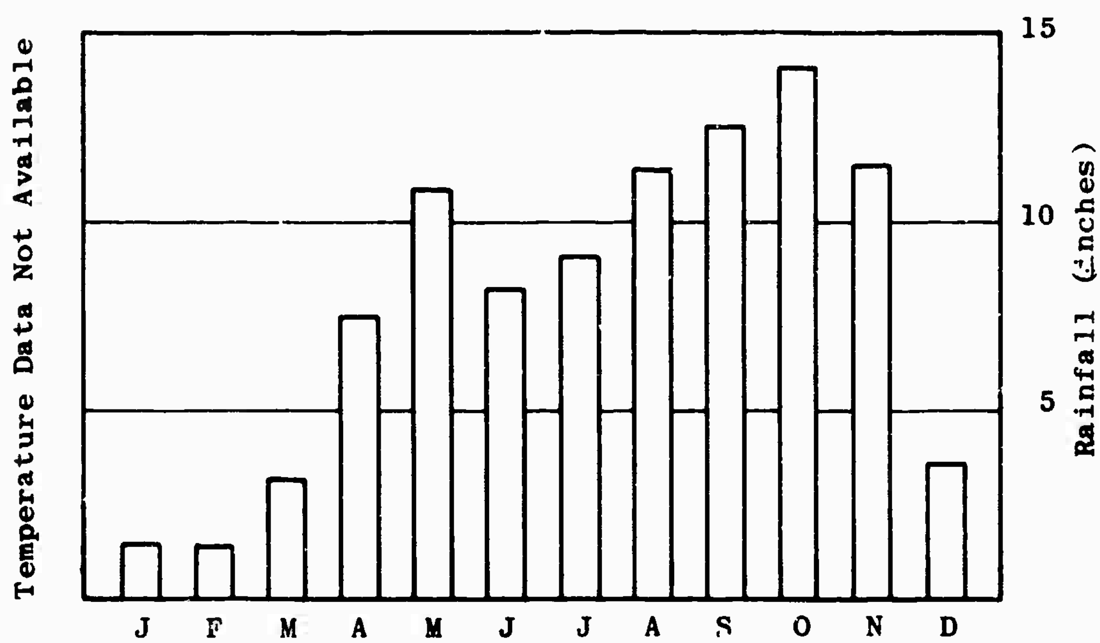


Figure 2.4 Terrain Profiles for Pak Chong Radials A and B



Pak Chong Test Area
(63" total measured annual rainfall)



Songkhla Test Area
(95" total measured annual rainfall)

Figure 2.5 Comparison of Rainfall at Pak Chong and Songkhla Test Areas

Semiannual Report Number 7. For more detailed vegetative data, it is expected that the Military Research and Development Center in Thailand will soon conduct an intensive environmental study of the Songkhla test site, similar to the one it made at the Pak Chong test site.

Based on the figures in the Site Survey Report, a preliminary comparison can be made of the jungles at Pak Chong and Songkhla. In regard to radio propagation, the most important characteristics of the vegetation are its average height and density. These characteristics are summarized in Table 2.1.

Table 2.1

VEGETATIVE CHARACTERISTICS OF TWO SITES IN THAILAND

		Location	
Characteristics	Unit	Songkhla	Pak Chong
Biomass	Tons Per Acre	309	130
Total Trees	Per Acre	606	362
Height Class			
6-16 m	Trees/Acre	434	290
17-29 m	Trees/Acre	71	62
30-50 m	Trees/Acre	81	10
Vines, 5 cm	Vines/Acre	20	-
Upper Canopy Density	% Crown Cover	60-80	< 20

The first row in Table 2.1 gives the "biomass," which is an estimate of the tons of plant life per acre. Since the biomass figure is a rough approximation, based on measurements of tree density and trunk diameter, it is only necessary to note that the weight density of the Songkhla jungle is about 2.5 times that of the Pak Chong jungle.

The other rows of Table 2.1 show that this great increase in weight density is caused both by a greater number of trees and by a greater average tree height. Altogether, there are about 70 per cent more trees per acre at Songkhla. However, at Songkhla there is an 800 per cent increase in the largest and heaviest class of trees, which are those ranging from 100 to 160 feet high. This eight-fold increase in the highest trees has meant that 120-foot masts are needed at Songkhla to raise the antennas to an elevation where there are only scattered treetops, whereas at Pak Chong an 80-foot mast was sufficient for this purpose.

2.2 Test Program Support System

After the test area was located and the test program worked out, it was necessary to devise the most efficient system for conducting the tests. As the word "system" is used here, it means the over-all arrangements for maintaining, transporting and utilizing the requisite personnel and equipment.

When this system was being devised, its features were strongly influenced by three basic considerations: the desirability of keeping the logistical needs, the facilities investment, and the equipment investments as low as possible.

Since the test area was about five times as far ›m Bangkok (from where most supplies are sent) as Pak Chong, the logistics cost would be far higher than at Pak Chong if as many supplies had to be shipped in. Moreover, the site itself can only be reached over a 12-mile dirt trail which is impassible for most vehicles during about nine or ten months of the year. These conditions tended to make the supply system both costly and unreliable. Therefore, it was advantageous to reduce the logistics requirements as much as possible.

The reason for desiring to keep the facilities investment low was the relatively short duration of the Songkhla tests, which are scheduled to last about nine months. The Pak Chong tests, lasting a number of years, justified the building of a large and complete group of semi-permanent facilities, whereas the shorter Songkhla tests did not.

In attempting to keep the equipment investment low, there was not only an immediate reduction in costs to be gained, but also a decrease in the facilities and supply system needed to support this lesser quantity of equipment.

The support system that resulted from these and other considerations comprises a base site at the center of the Songkhla test area, a supply depot located at the junction of the access trail and the paved highway, rented quarters in the town of Songkhla, and transportation to tie these units together.

Company field personnel reside in the town of Songkhla and fly daily to and from the test site by helicopter. The helicopter is also used to transport receiving equipment for the longer range propagation tests. The base site contains the test equipment and quarters for the Thai personnel. Provisions for the base site are trucked to the supply depot on the paved highway, and from there Rolligon vehicles carry the provision over the dirt trail to the base site. Since most tests are conducted with "man-pack" or man-carried rather than vehicularly transported equipment, there are fewer vehicles in use at Songkhla than was the case at Pak Chong. This system of transportation and facilities, which is further detailed in Sections 2.2.1 and 2.2.2, has required a minimal investment in buildings and vehicles. It is operable under all normal weather conditions and is not paralyzed when any one part is temporarily out of order.

2.2.1 Logistics

As described earlier in the introduction, the Songkhla test area is situated in a section of extremely thick tropical rain forest in the southern peninsula of Thailand, about 500 miles from Bangkok. Figure 2.6 is a map of part of this peninsula, showing a cross hatched area which represents the test area. The towns of Satun, Haadyai, and Songkhla are also marked on the map. The railroad connecting Songkhla and Haadyai extends north from Haadyai to Bangkok. Approximately 20 hours are needed to make the railroad trip from Haadyai to Bangkok. Supplies intended for the Songkhla test site are unloaded at the Haadyai

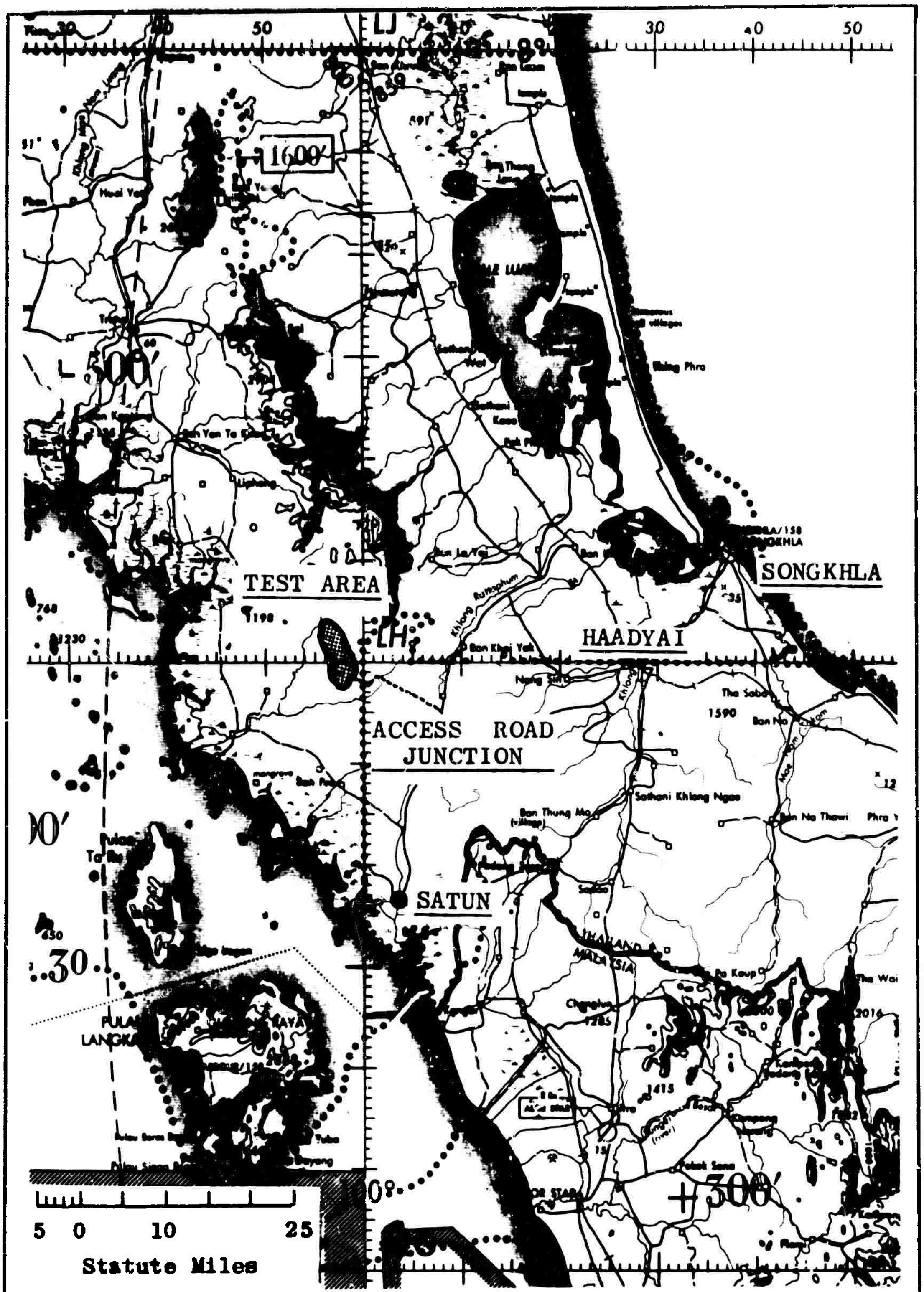


Figure 2.6 Map of Songkhla-Satun Region

terminal and transported by truck down the paved highway between Haadyai and Satun to the point where the unpaved road leading to the test site meets the highway.

Figure 2.7, a map of the region surrounding the test area, shows the last few miles of the dirt road leading to the test site. Since it was originally constructed to provide access to the Kuan Karlong Development Area, the road ended at the point marked "B." To construct the base site, this road had to be extended an extra two miles by the contractor.

The heavy and almost continual rainfall imposes severe constraints on the use of the unpaved road. During construction of the Pak Chong site it was found that normal vehicles would turn such trails into impassable morasses of mud during the wet season. Therefore, it was decided to use helicopter transportation insofar as possible at Songkhla for ferrying in personnel and less bulky items to reduce wear on this trail. Those things which have to be transported down the unpaved road from the temporary depot are carried on Rolligons. These vehicles, one of which is shown in Figure 2.8, use very wide tires having inflation pressures of about one pound per square inch. The flexibility and large load carrying area of these "air bag" type tires give the Rolligon two great advantages over other types of vehicles. First and foremost, it can get through where no other vehicle can; and secondly, it does not further tear up or rut the ground it passes over.

Before the Rolligons arrived at the Songkhla site, the 25-mile unpaved road had been so rutted by trucks

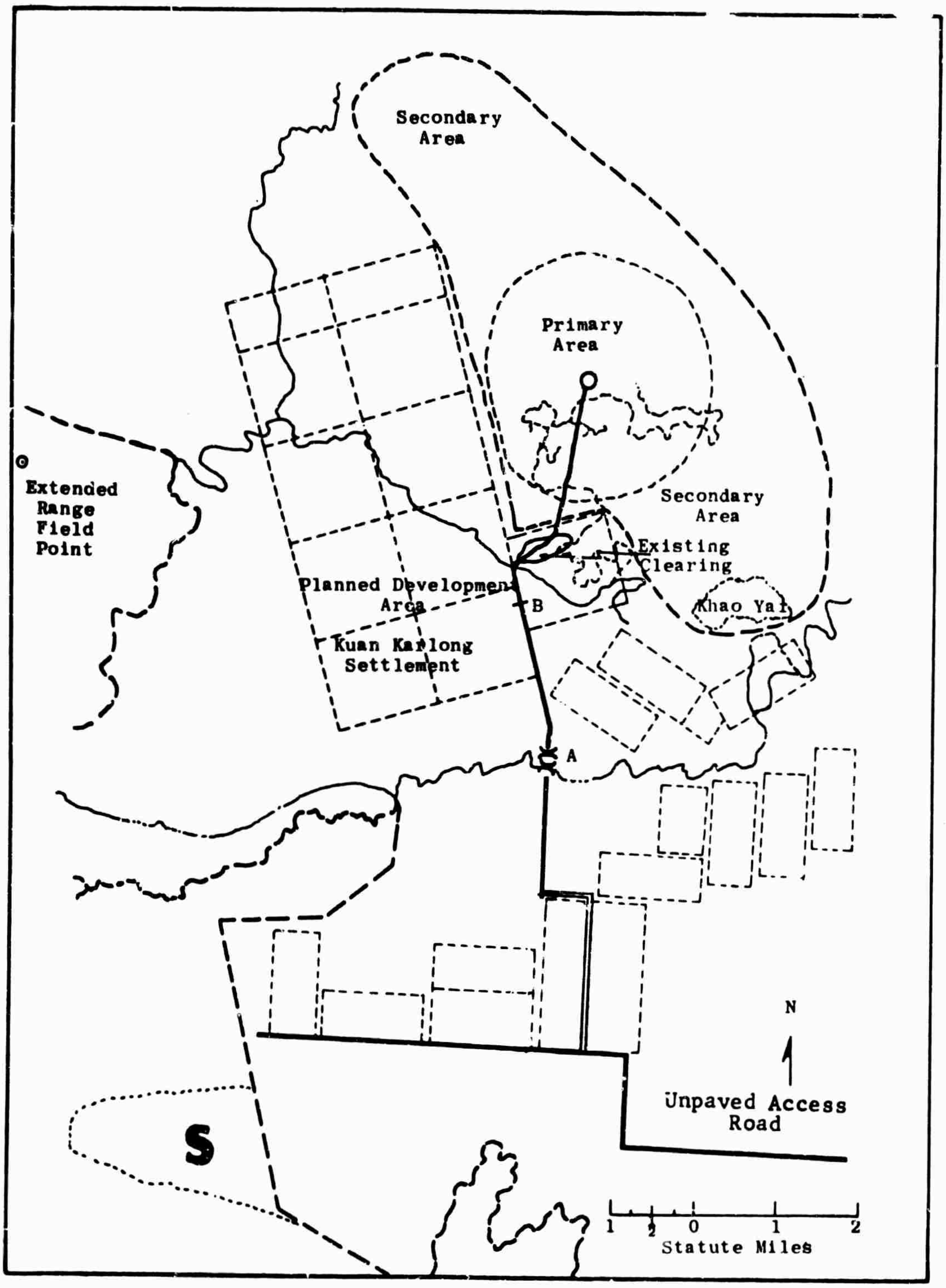


Figure 2.7 Map of Test Area

Figure 2.8 Rolligon "Marsh Skeeter" Carrying Supplies along Access Trail

carrying in construction materials, that two days and the assistance of winches were required to reach the base site. Though the trail had already undergone rebuilding operations, it had deteriorated again. The Rolligons, by contrast, were able to make the distance in under two hours without winching, and have not caused any more deterioration of the trail.

While the over-all transportation system for the test site required a good deal of careful planning and comprised a variety of transports, it has proven to be not only very effective and reliable, but also flexible when the need arises.

The railroad brings supplies from Bangkok to Haadyai and Songkhla. This transportation link is supplemented by a plane which flies weekly between Bangkok and Songkhla. Bulky supplies intended for the test site are unloaded from the train at Haadyai, trucked to the depot at the junction of the site access road, and carried by Rolligon vehicle the rest of the way to the site. At present, all fuel, construction material, non-breakable technical equipment, food, and other routine supplies are carried to the site by this method.

The other transportation system for the test site is the helicopter which flies daily from Songkhla to the base site. From their rented lodgings in Songkhla, the Company's engineers and technicians commute daily to the test site by helicopter. The helicopter is also used for quick delivery of smaller items. The air distance from the Songkhla airport to the base camp is about 50 miles. Presently, the helicopter is not assisting in the measurements themselves, for all tests are now being conducted on foot path trails within a mile and a half of the test site. Later, when tests are made in the secondary area, 2 to 8 miles from the transmitter site, the helicopter will be used to transport men and equipment to the different receiving sites.

In the event that the helicopter becomes inoperable or unavailable, there are provisions to keep the test programs operating for a period of time. The depot at the junction of the access trail and the paved road has sleeping quarters and rations for the test personnel who normally fly in from Songkhla. The depot itself can, of course, be supplied by truck from Haadyai or Songkhla, and the men travel to and from the transmitter site by Rolligon vehicles. These quartering and feeding arrangements are planned for temporary and emergency use only. So far they have been used a few times when the helicopter required repairs or when it was urgently needed elsewhere, as happened during a week of unusually heavy rains and flooding in January.

Figure 2.9 is a symbolical diagram of the over-all logistical network.

2.2.2 Facilities

The facilities for the Songkhla tests include buildings at the transmitter site for housing the equipment and Thai support personnel, the depot building on the highway, and the rented housing in the town of Songkhla. Most of the facilities in town are lodgings, though there is

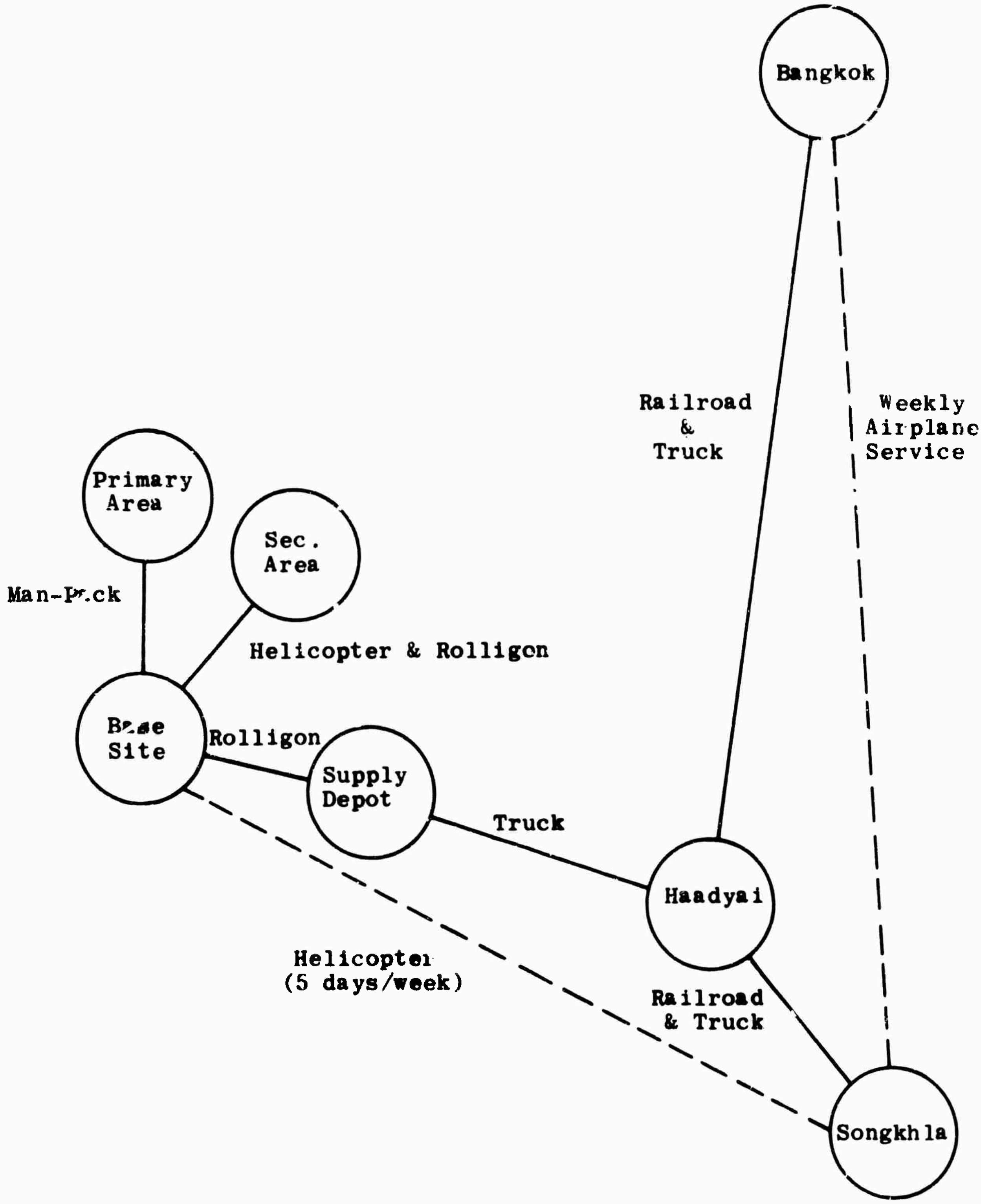


Figure 2.9 Transportation and Supply Network

also a small secondary field administrative office, which functions under the Bangkok office and is used to do work that does not need to be sent to Bangkok.

Figure 2.10, a detailed drawing of the construction plan of the Songkhla base site, shows the oblong shape of the site, which has helicopter pads at both ends so that the pilot can adjust his approach according to wind conditions. Since as few trees as possible were cut down, the air descent into the site is difficult, and it is important for the pilot to have some choice of landing direction under heavy winds. Figure 2.11 shows two aerial views of the base site.

The main functional units of the base site are the living and eating facilities for the Thai police and support personnel, the operations buildings where the transmitters are housed, and the vehicle repair and parking building. Other facilities are for power generation, fuel, water, police operation, waste disposal and sanitation. The access trail visible in the drawing is approximately 12 feet wide, and bridges along the trail are capable of supporting a 10-ton load. Within the base clearing, stumps have been cut to ground level and some areas are covered with crushed rock, as shown in Figure 2.10.

About 25 Thai personnel, 10 police and 15 support, are quartered at the base site. The police headquarters building contains an office, communications equipment, and sleeping accommodations for three persons. Both the police and support personnel use the same buildings for living and eating.

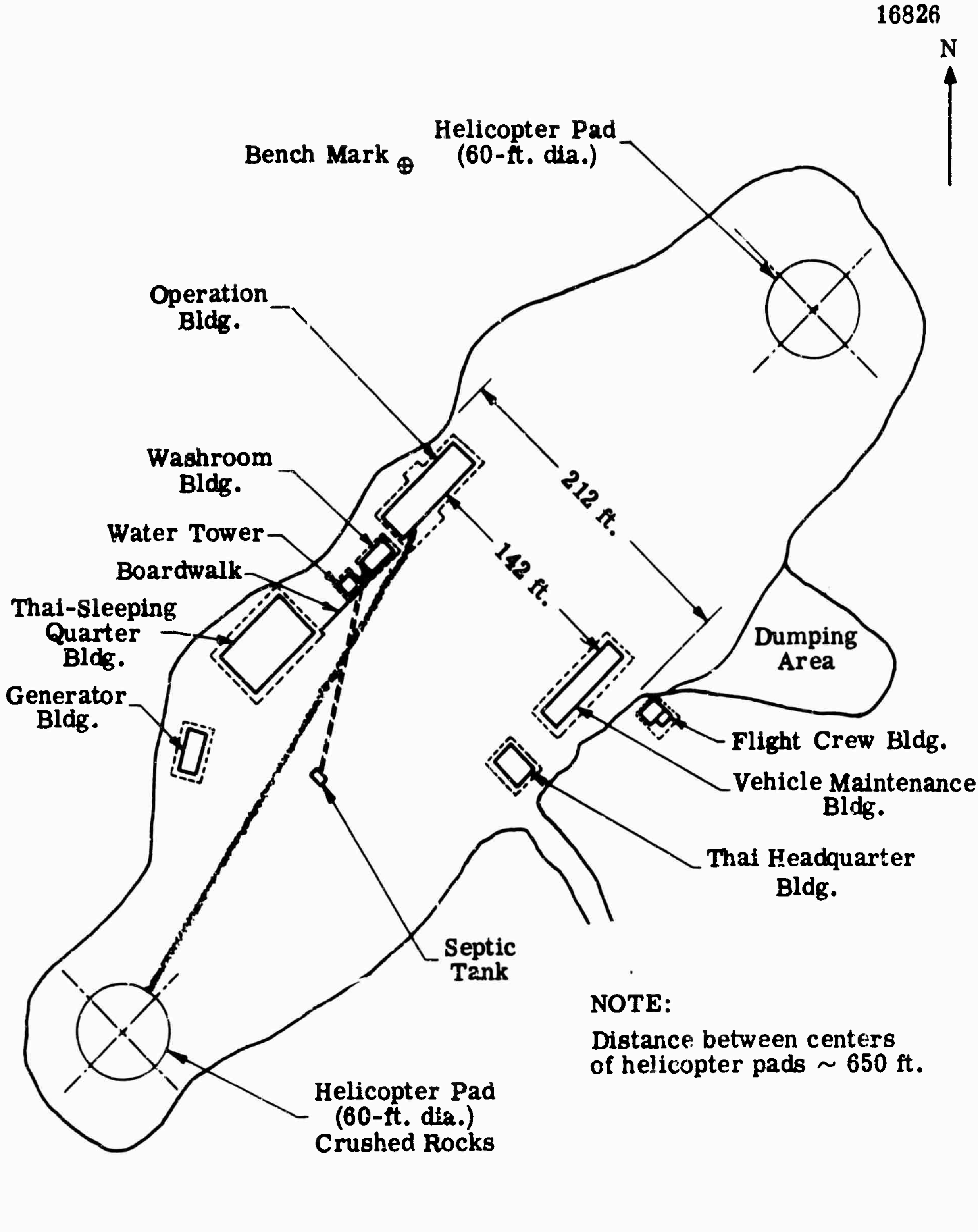


Figure 2.10 Building Plan of Songkhla Base Site

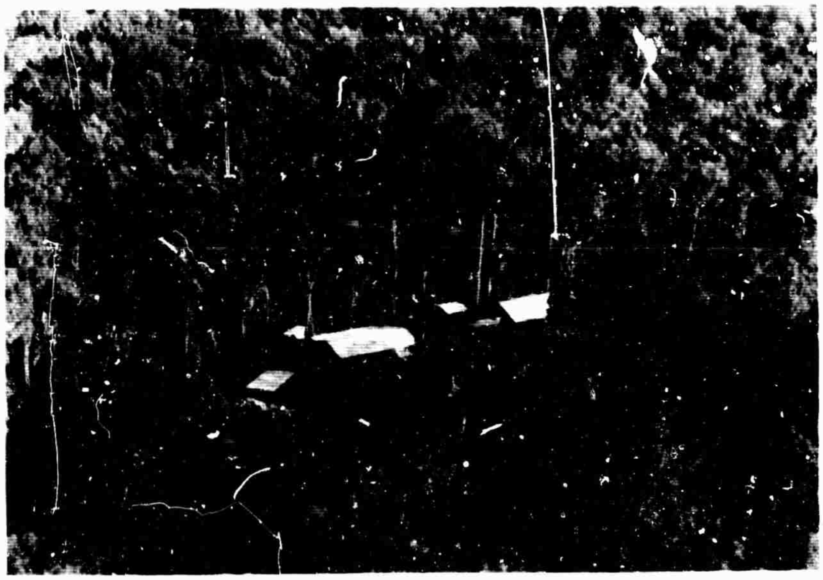


Figure 2.11 Aerial Views of Songkhla Base Site

The operations building shown in Figure 2.11 is air conditioned to protect the transmitters and help maintain calibration. By constructing an air conditioned building, it was not necessary to transport in the air conditioned transmitter shelters that were used at Pak Chong. Figure 2.12 is a photograph of this building, which gives some indication of the relative height of the jungle at Songkhla. Figure 2.13 shows the supply depot with the Rolligon taking on provisions.

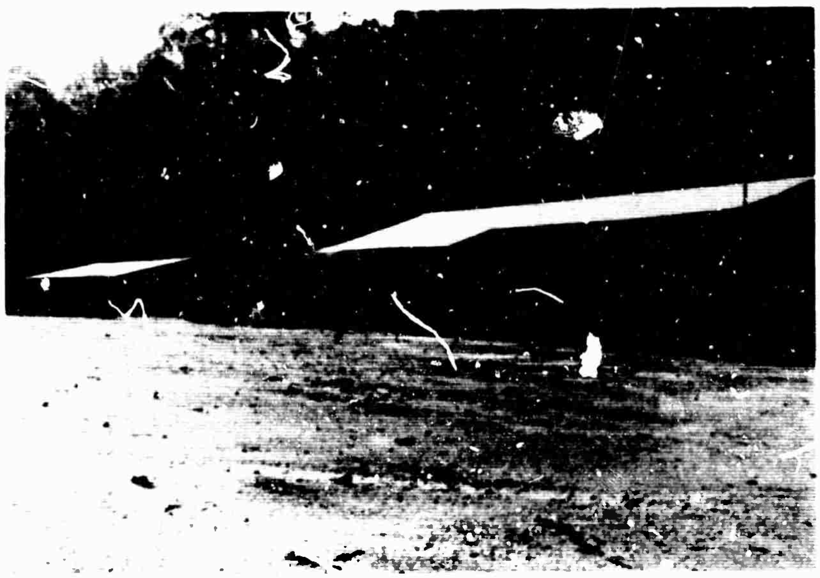


Figure 2.12 Operation Building at Base Site

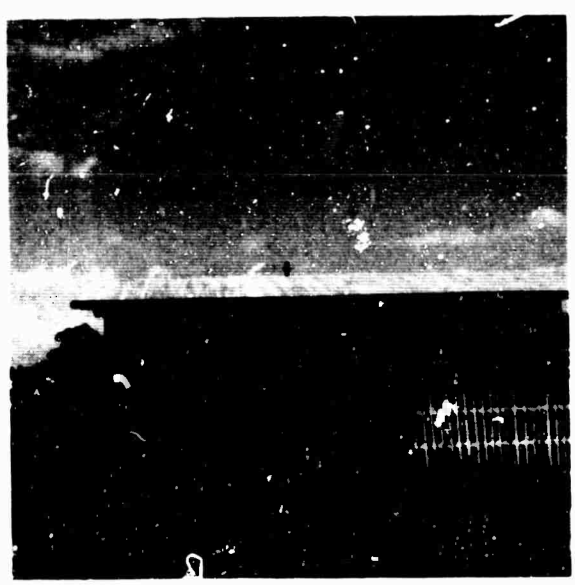


Figure 2.13 Supply Depot (and Emergency Quarters) at Junction of Access Road

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3. TEST PROCEDURES

The extensive Pak Chong measurements have defined the propagation characteristics of a wet-dry tropically foliated environment classified as a dry or semi-evergreen forest. Many samples were taken over variables such as frequency, distance, height and polarization. This data, however, represents only one sampling of climate and vegetation. Additional samples in a rainy tropical jungle are needed in order to develop the comprehensive prediction models for a variety of different tropical environments.

An important consideration in developing the test procedures for the Songkhla area was that it is not necessary to repeat the full measurement sequence employed in the Pak Chong area. The Pak Chong measurement results have given strong indications of what factors are of lesser significance. Extensive use has been made of the basic information learned from the Pak Chong data throughout the development of test procedures for the second area.

The most important single fact learned from the Pak Chong data is that the significant differences between a foliated and a comparable non-foliated area show up close to the antennas. As propagation distances are increased, propagation losses increase in the manner which has been observed for non-foliated terrain, retaining the constant bias introduced at close separation distances. Therefore, in Songkhla the measurements are concentrated at the closer distances within the vegetation in order to better understand propagation phenomena near the antennas. However, some measurements are made at the larger separation distances, to correlate with the Pak Chong data, and to determine whether or not propagation characteristics continue to fall off in this type of vegetation in the expected manner.

Thus, the concept of a primary test area which is relatively close to the transmitting site, and a secondary test area which encompasses more distant test points has been adopted.

3.1 Primary and Secondary Measurement Locations

The function of the measurements being made in the primary test area is to investigate short-range radio propagation through the jungle. This area is approximately circular, and contains four radial walking trails extending outward about one and a half miles from the transmitting antenna. There are 13 special field points within the primary test area at which field strength measurements are made as a function of receiving antenna height. These 13 field points within the primary area are spaced along the four radial trails.

Although some equipment will be flown by helicopter to the field points in the secondary area, only hand-carried or man-pack equipment is used on the radial trails themselves. This procedure is entirely adequate for the task and has eliminated the construction work necessary to build vehicular trails.

The basic tests on these walking radials are made with 13-foot-high transmitting antennas and hand carried, 6-foot-high receiving antennas. However, other tests are made with the transmitting antennas raised to heights of 40, 80, and 120 feet, and with ground plane, vertical monopole antennas for certain frequencies.

There are numbered markers along each of the four walking radials. The number of each marker, when multiplied by 100, gives the number of feet to the bench mark, which is the center point of the four radials.

At the end of this report period, construction work on the secondary test area had just begun. Therefore, it is not now possible to precisely describe the locations of all the secondary test points. Figure 3.1 shows the locations of the four radial trails, W, X, Y, and Z, and of the four field points, FP-A, FP-B, FP-C, FP-D, that have been determined so far.

3.2 Test Plans and Procedures

This section of the report describes the different propagation phenomena that are being measured or are planned to be measured. Where applicable, the particular procedures for making certain measurements are also outlined.

3.2.1 Path Loss as a Function of Distance and Frequency

The objective of this measurement series is to determine the way in which path loss varies with distance and frequency. Most tests will be made with low (approximately 6-foot) receiving antennas. This section discusses the experimental and environmental parameters that are to be considered in these tests. One very important part of these tests is the problem of getting a representative value

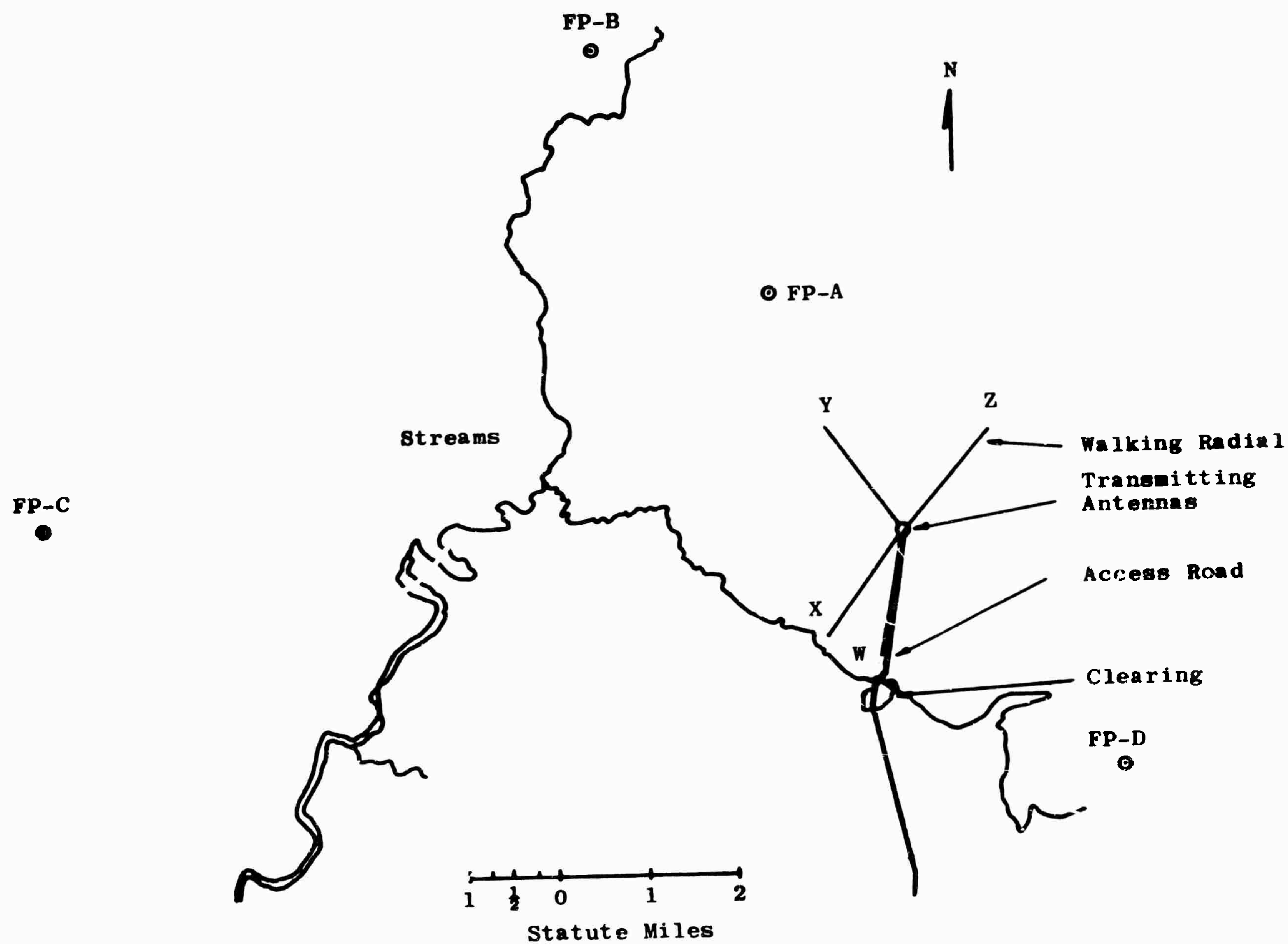

Figure 3.1 Locations of Walking Radials and Field Points

of median field strength and of the degree and nature of signal variation around the median value.

The horizontal distance between the peaks and nulls of variations around the median value is on the order of a half wavelength of the particular frequency. However, even after extrapolating the median value from these spatial variations, there is another kind of variation associated with the median value itself. This variation is more gradual. It is caused by irregularities in the terrain. In the plots of path loss vs. distance in Section 4, the irregularities of the path loss envelopes reflect the slower variations in the median values. These two variations, called rapid and slow variations, and the means of measuring them are discussed in Section 3.2.2.

The range of transmitting antenna heights in these tests will be ground level (for vertical monopoles), 13 feet, 40 feet, 80 feet, and 120 feet. This last height is above all vegetation except for a few isolated treetops.

In tests made so far on the four walking radials, vertical and horizontal dipoles have been used at 13, 40, 80, and 120 feet for frequencies of 50 and 100 Mc/s. However, in no cases has any one frequency been used at all the scheduled combinations of height, polarization, and transmitting path. At 50 Mc/s, some measurements have been made using a ground based vertical monopole.

Because the behavior of signals whose frequencies are below 25 Mc/s has not shown many effects of foliage, there will not be as many lower frequencies tested as there were at Pak Chong. Present plans call for tests at 0.880, 2, and 12 Mc/s, leaving out the 0.100, 0.300, and 6 Mc/s measurements made at Pak Chong.

As mentioned earlier, these tests are to be conducted in the primary and secondary test areas. It is expected that the short-range, primary area tests will yield desired information about antenna height gain, "through-the-foliage" attenuation and "treetop mode" attenuation. Later tests in the secondary area are expected to provide further data on propagation loss of the treetop mode. In both primary and secondary areas the received signal will have substantial spatial variations, and special measurements will be needed to determine median values of received field strength.

3.2.2 Field Strength Variation

At Pak Chong there was found to be a significant and complex spatial variation in received field strength. It is expected that the same basic behavior will also exist at Songkhla, though the difference in foliage will somewhat alter the magnitude and spread of the variations.

Tests at Pak Chong indicated that there was no significant variation in foliage for frequencies below 25 Mc/s; therefore, only a few samples will be taken for these frequencies at Songkhla to see if, as expected, the same condition holds. However, as frequency increases, both the rate of change and the magnitude of the variations increase. Continuous vehicular recordings made at Pak Chong have shown that, as these variations become more pronounced, they can be seen to have two separate or distinct components, one, a so-called "rapid" variation and the other a "slow" variation. Figure 3.2 gives a good idea of how these two components are superimposed upon each other. The slower variation, shown by the dotted line on Figure 3.2, is characteristic of propagation in rough terrain; whereas the rapid variations are caused by more closely spaced obstacles such as vegetation or buildings. The continuous recorder has a nonlinear dB scale, shown on the left of Figure 3.2, and the extreme variations on the upper part of the chart should be considered in terms of their dB values.

To measure the rapid variations, a number of closely spaced samplings will be made. The purpose of these samplings will be to determine the distance between peaks and nulls. Measurements at Pak Chong indicated that the peak-to-null spacing, or half cycle width, is about 0.37 wavelength for frequencies from 25 to 400 Mc/s. Table 3.1 indicates what some of these distances are.

Table 3.1

PEAK-TO-NULL DISTANCES FOR RAPID VARIATIONS

Freq. (Mc/s)	Average Distance (ft)	Average Distance (wavelengths)
25	14.6	0.371
50	7.3	0.371
100	3.6	0.366
250	1.5	0.381

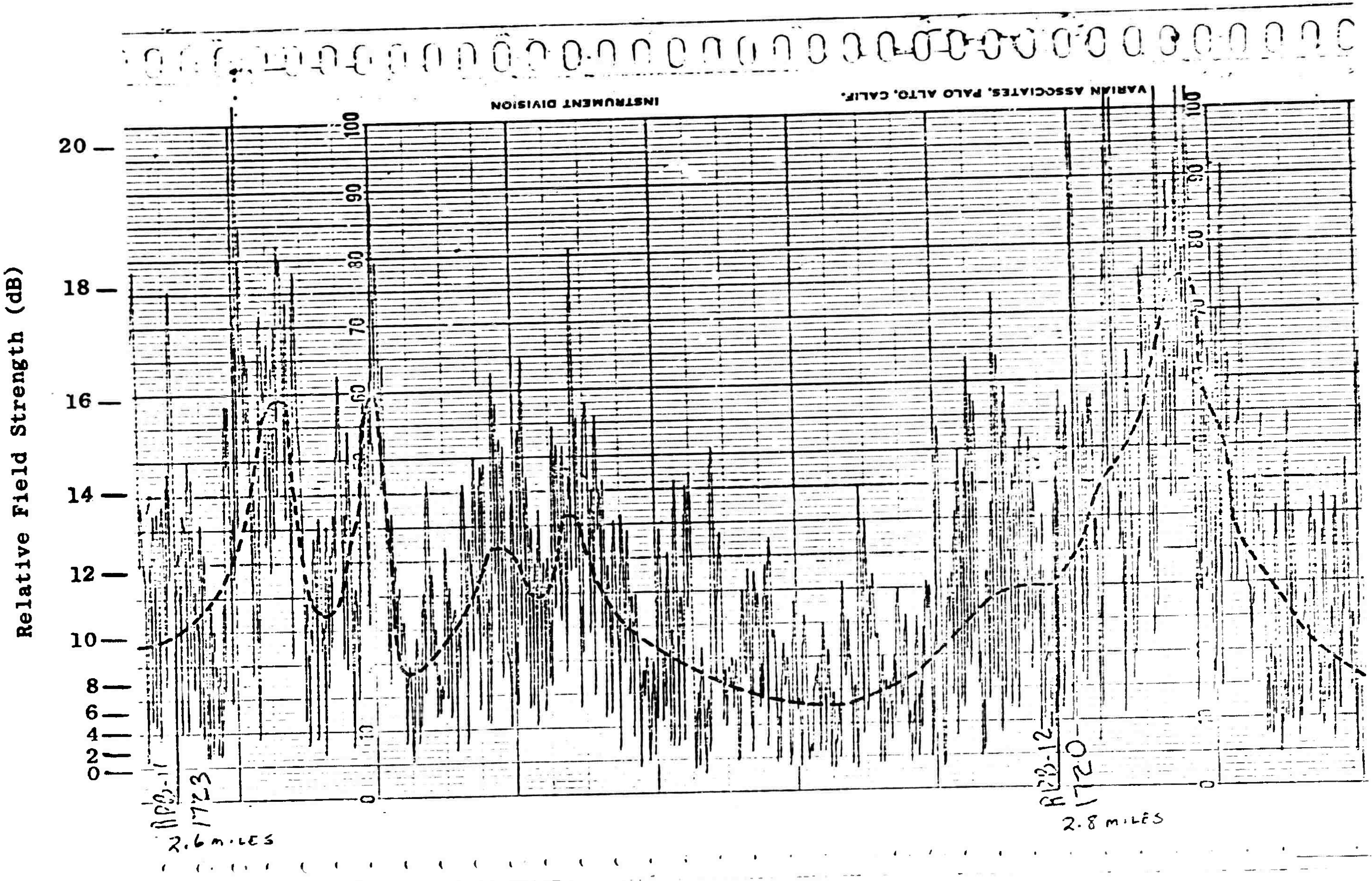

Figure 3.2 Example of Rapid and Slow Data Variations -- From Pak Chong Measurements

Samples of the rapid variation will be taken at a number of randomly chosen points along the four walking radials and also at several locations in the secondary test area. Measurements using both horizontal and vertical polarizations will be made. The measurement at each sampling location will be carried out in the following manner. Maximum and minimum field strength values will be determined over a 6- to 10-foot interval. Where peak-to-null distances are too long to show up, or where the readings are erratic, five spot measurements will be made. However, at higher frequencies, where very rapid changes can be expected, more than five readings will be made in order to detect peaks and nulls. The distances and signal levels associated with these readings are recorded in log books, and later transferred to punched cards and analyzed by computer.

The other type of variation encountered in the path loss measurements is the "slow" variation caused by uneven terrain. As defined in this context, the value of the slow variation is the median value of the received signal, taken over a few cycles of the rapid variation. It is this slow variation which is used to plot the fall-off in signal strength with distance. From these slow variations of median field strength, either smoothed or average curves of median values can be generated.

To get accurate readings of the "slow" variation, it is necessary to measure through the rapid variations. These measurements will be made for vertical and horizontal polarizations at the normal test frequencies.

Since data from Pak Chong shows no significant rapid variations below 25 Mc/s, it is not expected that there will be any need to use special measuring techniques at these lower frequencies. However, above 25 Mc/s there are two alternate sampling techniques that will give desired median values. One of these, which is preferable when probing can detect definite maxima and minima, is as follows. The approximate distance required to traverse one rapid variation is determined for the frequency of interest from the samples taken of the rapid variation. The antenna is then moved either forward or backward along the foot path for a distance of at least one, or if practical, of several cycles. The maximum and minimum fields over this distance are recorded along with a median distance associated with the probed area.

In certain instances this procedure may be unsatisfactory because the distances required may be excessive or because it may be difficult to establish a definite maximum or minimum. In these cases, a second sampling procedure may be employed in which a strip of trail is chosen covering several cycles of the expected average rapid variation. Over this distance, the field strength at several random points will be determined. These readings are recorded for later reduction to punched cards. It is not necessary to record the exact distance at which each sample was taken. A median distance associated with the probed area is sufficient.

The type of information shown in Figure 3.3 will be used to determine the number of samples to be used whenever the discrete sampling procedure is followed instead of the probe method. The abscissa on this figure represents

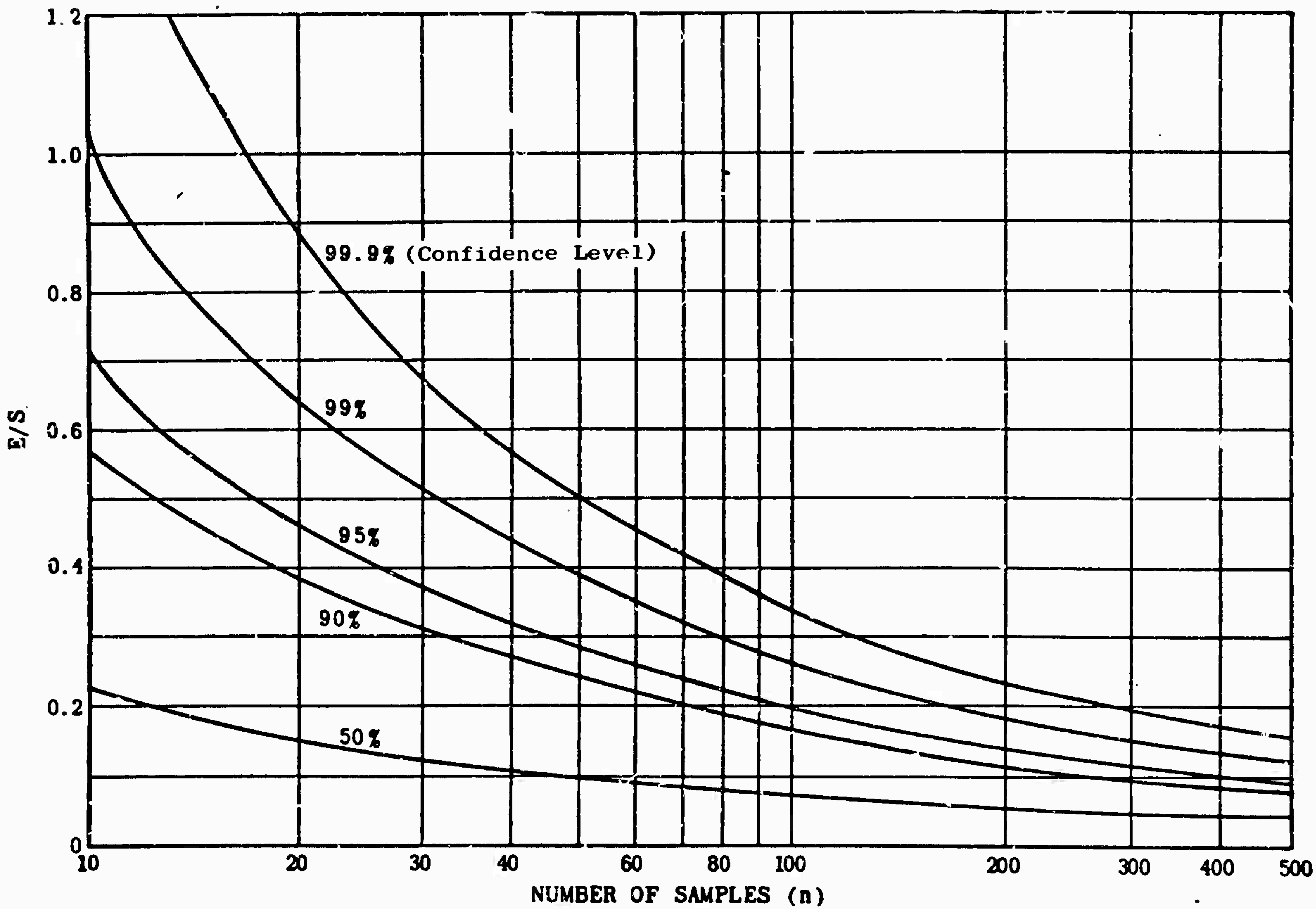

Figure 3.3 Normalized Error in the Mean, with Unknown Standard Deviation

the number of samples taken in any small area. The ordinate E/S is a measure of the possible error in the mean value based on n samples. The parameter on the curves is the confidence that the error indicated by the ordinate is not exceeded. The term E is the dB error in the estimated mean value, and the term S is the standard deviation which is estimated from n samples.

The Pak Chong data indicates that typical standard deviations could vary from 2 dB to about 6 dB. As an example, consider a standard deviation of 4 dB and assume 10 samples are taken. Then, at the 90 per cent confidence level for n=10, Figure 3.3 shows that E/S=0.57. The estimate of S is 4 dB, hence E=E/(S)S=2.28 dB. This means that under the conditions stated it is 90 per cent probable that the error in the estimated mean value is less than 2.28 dB. In a similar manner, with 10 samples it is 99 per cent probable that the error is less than 4.04 dB. By using 20 samples, the possible error drops to 1.6 dB at the 90 per cent level and 2.56 dB at the 99 per cent level.

3.2.3 Path Loss as a Function of Antenna Height

The objective of these tests will be to define height-gain profiles for direct comparison with the over-all height-gain characteristics observed in the Pak Chong tests.

Minimum and maximum antenna elevations in these tests will be from 6 to 120 feet, at which height there are only isolated treetops. In the course of the walking measurements, a limited number of height-gain tests using the transmitting antennas will be made over the frequency range of 25 to 250 Mc/s at heights of 6 feet (or ground level for the vertical monopoles), 13, 40, 80, and 120 feet. However, the larger horizontal and vertical dipole transmitting antennas are not able to approach ground this closely; and, of course, the ground plane, vertical monopole transmitting antennas cannot be elevated at all. Therefore, the main portion of the height-gain measurements will be made with the smaller receiving antennas which can be more easily elevated.

The general procedure for these measurements will be to mount the receiving antennas on the portable masts and to raise the mast over the distance of one tube section, about 5 to 6 feet. Each time the antenna is raised an additional height increment, a field strength reading is taken. If a significant peak or null or both are noted while the antenna is being raised, the quantities are also recorded. From this information, median field strengths will be determined for different heights. Seventeen field points have been cleared for making height-gain measurements with receiving antennas. Thirteen of these points are spaced along the walking radial trails. Table 3.2 lists the transmission distances and trail locations for these field points on the walking radials. Four other, more distant field points have been constructed for longer range height-gain measurements. These points are located about 2 to 8 miles from the transmitters, and can be seen in Figure 3.1 where they are labeled FP-A, FP-B, FP-C, and FP-D.

The data, after it is recorded and converted to units of path loss, will be analyzed in the same way as was the fixed point data from Pak Chong.

Table 3.2

FIELD POINT LOCATIONS ON WALKING RADIALS

Radial Trails	Transmission Distance (miles)
W	0.45
W	1.0
X	0.2
X	0.45
X	1.1
Y	0.10
Y	0.45
Y	1.0
Y	1.5
Z	0.05
Z	0.20
Z	0.70
Z	1.5

3.2.4 Attenuation for Short Paths Directly Through the Foliage

The Pak Chong data indicates that the primary mode of propagation in the jungle involves transmission along the tops of the trees. After an initial loss due to the proximity of the antennas to foliage and the attenuation of radio waves which travel through the foliage, the field appears to follow a conventional diffraction mode. The objective of the series of tests discussed here is to assess the attenuation experienced by waves which travel directly through the foliage. These measurements are to be conducted in a manner similar to the short-range 10-Gc/s measurements which have been made at Pak Chong.

These measurements are to be made from the lowest practical frequency (e.g., 550 Mc/s) up to 10 Gc/s. Horizontal, vertical, and cross polarizations are to be used. Antenna heights from near ground level to near treetop heights are to be employed.

A transmitting tower will be erected at the transmitting site and a receiving tower will be located within the foliage at several locations between 50 and 300 feet from the transmitting tower. The antennas will be separated from the foliage by at least $2D^2/\lambda$, where D is the maximum dimension of the antenna and λ is the wavelength.

Since there is a significant amount of time and small sector variability at the higher frequencies, the slider technique developed at Pak Chong will be used to obtain representative attenuation values for the different antenna heights and frequencies. For this, the slider is used to position the antenna at a number of locations over an area that will encompass the full range of spatial signal variations. At each location the reading will be taken for a long enough period to obtain a median value rather than a wind-induced variation.

3.2.5 Depolarization Measurements

Measurements using opposite polarizations for transmitting and receiving are made at several distances within the primary test area for all test frequencies. The objective of these tests will be to determine the degree of depolarization induced by the presence of foliage at the various test frequencies.

Figure 4.4 in Section 4 shows how polarization data is taken at selected measurement points on the walking radials, first with the receiving antenna aligned and then with it set +45 degrees, -45 degrees, and +90 degrees out of alignment.

3.2.6 Path Loss as a Function of Time

A few time recordings of received field strength in the primary test area are planned. Recordings are to be made simultaneously at a low receiving antenna height and at various elevations above and below treetop level. The recordings are to be made during windy and calm conditions.

The objective of these tests is to assess the effect of tree movement upon the variability of received field at treetop level. The results will be in the form of strip chart recordings with corollary data concerning wind conditions as a function of time.

3.2.7 Antenna-to-Vegetation Interaction Effects

The Pak Chong data provided indications of significant effects due to interactions between the antenna and the vegetation in close proximity, especially at the lower frequencies where the induction field extends into the vegetation. It is planned to conduct a series of tests with simple antennas to further assess these effects. The objective of this measurement series is to compare the performance of the lower HF and MF antennas in and out of the vegetation to assess the magnitude and nature of this proximity effect. Thus, two test sequences will be performed: one in the absence of vegetation, and one in the presence of vegetation. In both sequences, the antenna input impedance will be measured in addition to measuring the radiated fields.

3.2.8 Environmental Measurements

Measurements will be made of the over-all Songkhla environment to quantify those elements which affect radio propagation. Based on data from Pak Chong, it has been decided to get measurements of the climatic conditions, terrain roughness, and foliage distribution at Songkhla. Climatic conditions are not expected to vary significantly over the rather small and even measurement area. Therefore, most climatic measurements will be made only at the base site. An automatic rain gauge records precipitation at the base site. In addition, wet and dry bulb temperatures are taken at the base site in the morning, at noon, and in the late afternoon. This data will be reduced and analyzed using the same procedures applied to the Pak Chong data.

The terrain profiles of the walking radials have already been measured with a surveyor's transit and are shown in Section 2. They are also presented on the plots of path loss in Section 4. Additional measurements will be made to define the major terrain features between the transmitting antennas and the field points. However, the Songkhla area was specifically chosen to have as few major terrain features as possible so that the effects of vegetation could be more clearly seen. Thus, there will not be a need for extensive terrain measurements.

The vegetative measurements will be the most important environmental measurements undertaken at Songkhla. The vegetative parameters of greatest interest are the over-all weight density of the plant life, generally referred to as "biomass," the vertical distribution of the foliage, and the average foliage density as a function of height, called the foliage density profile. This data will be obtained by making the detailed measurements in several sample plots as was done at Pak Chong. To do this plot study, it is planned to request the Environmental Research Section of MRDC, which did the study at Pak Chong, to repeat its measurements at Songkhla.

4. PRELIMINARY MEASUREMENT RESULTS

Walking measurements are being taken on each of four radials which are 1.4 miles long and are centered near the VHF antenna pad shown in Figure 4.1. The geometry of these four radials, labeled "W," "X," "Y," and "Z," is also shown in Figure 4.1. Their radial orientations are as follows:

W - South 5^{o} west
X - South 35^{o} west
Y - North 35^{o} west
Z - North 40^{o} east

Measurement points have been surveyed along each radial according to the following schedule.

Every 50 feet for $0 \le d \le 1000$ feet
Every 100 feet for $1000 \le d \le 2500$ feet
Every 200 feet for $2500 \le d \le 4900$ feet
Every 500 feet for $4900 \le d \le 7400$ feet

There is a total of 52 measurement points on each radial. The points are numbered such that multiplying the point number by 100 gives the radial distance in feet. Thus, point 8.5 is located 850 feet from the center point, and point 49 is 4900 feet away. Figure 4.2 is a photograph of the first measurement point on Radial Y. At the right of the figure, the radial trail can be seen extending through the vegetation.

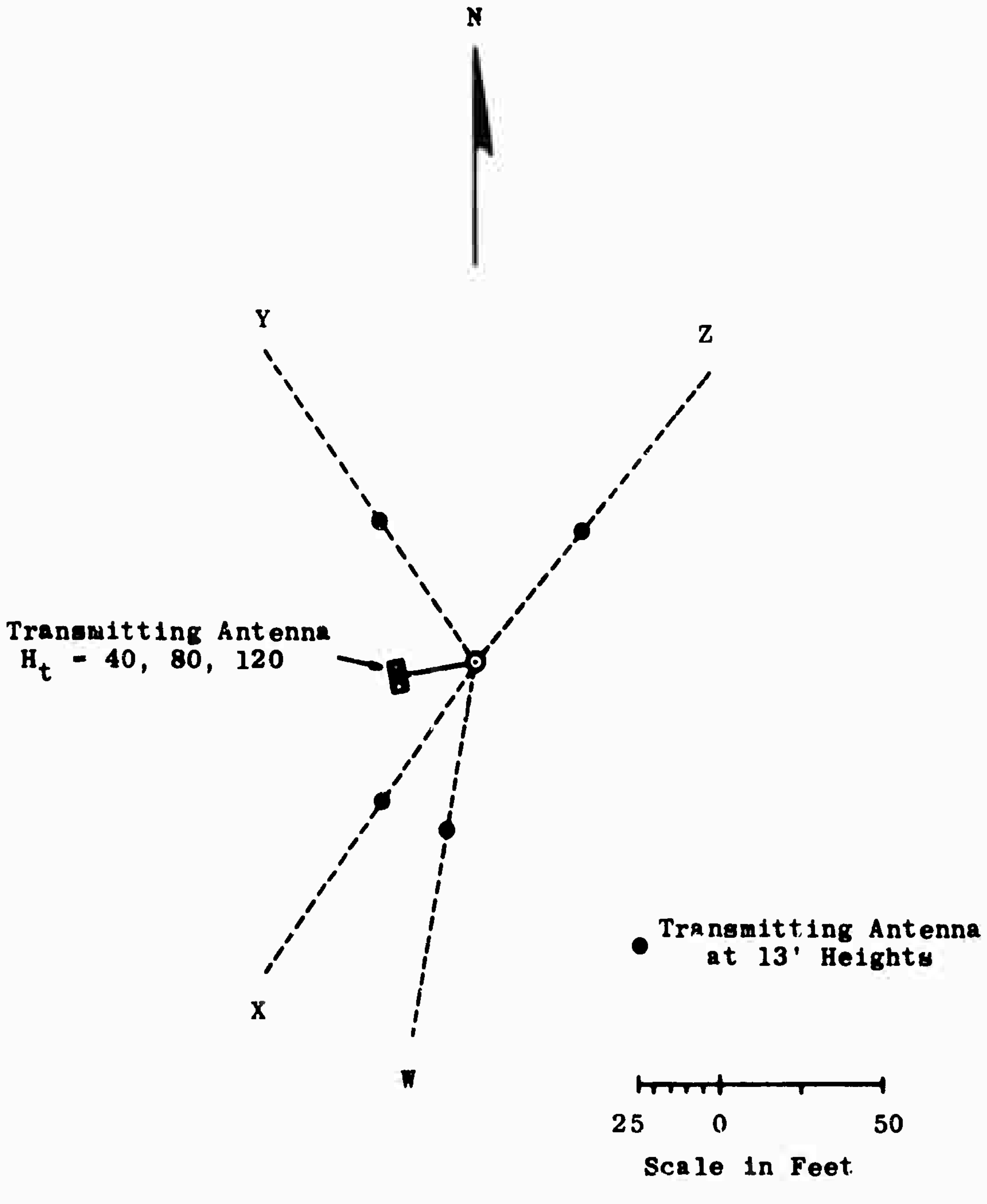

Figure 4.1 Layout of Radial Trails and Transmitting Antennas

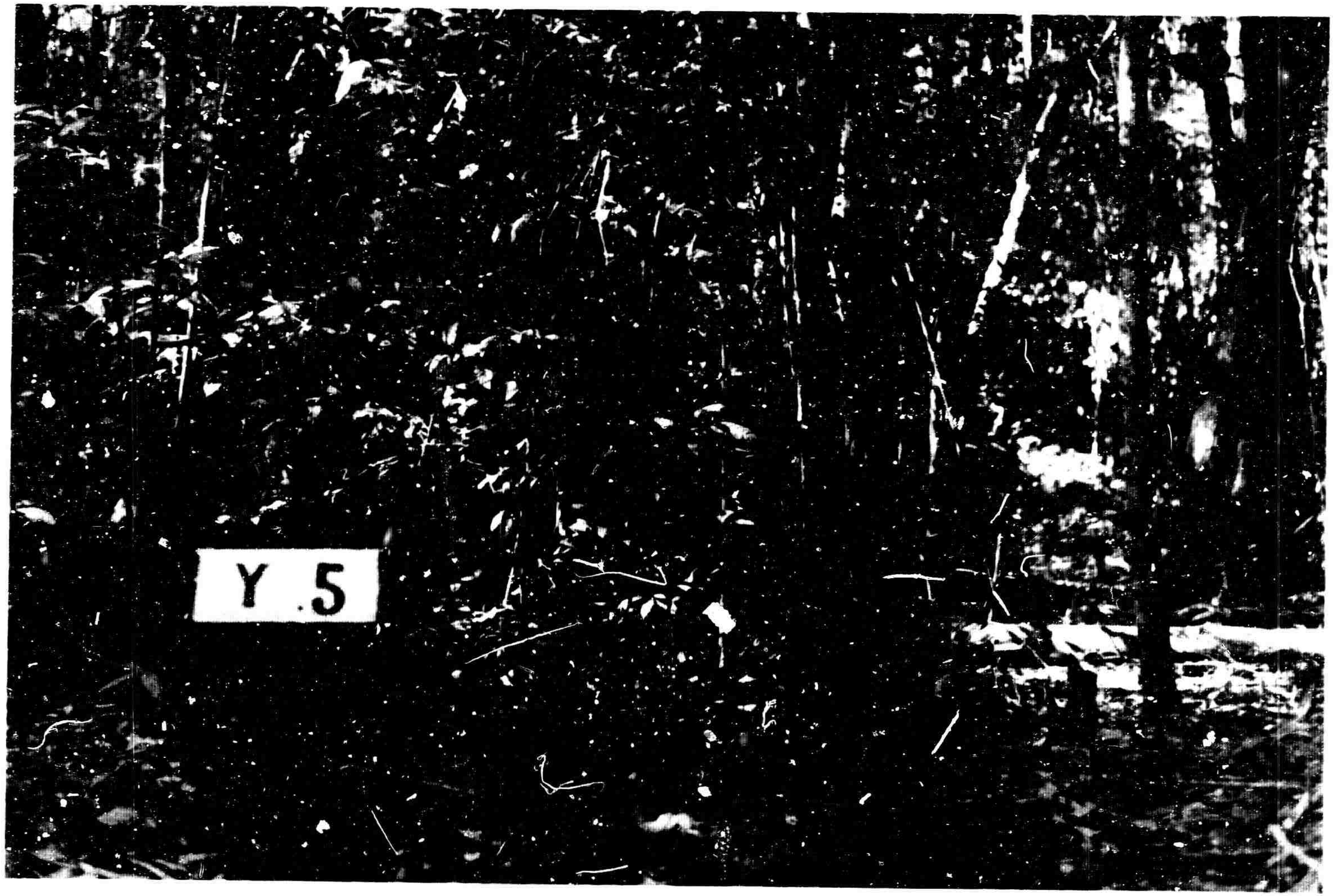

Figure 4.2 Typical Measurement Point on a Walking Radial

The lowest transmitting antenna height (13 feet) cannot be used at the VHF pad. Therefore, these low antennas are located at the first measurement point on each radial. If the 13-foot antennas are transmitting, the distance to the receiver point is equal to the point number times 100, minus 50 feet. For example, the distance to point 8.5 would be 800 feet.

A slight error in distance as computed above is present at the first few measurement points. This occurs because the VHF pad is slightly displaced from the bench mark (BM) which serves as the center of all radials as shown in Figure 4.1.

Table 4.1 provides a comparison between the nominal distance and the actual line-of-sight (LOS) distance for a sampling of the measurement points. The actual line-of-sight distance includes the effects of the different locations for each 13-foot antenna, the different antenna heights, and the slight offset of the VHF pad. The entries in Table 4.1 verify the intuitive concept that differences between nominal and actual distances can be significant at short distances but, as distance is increased, the differences in path length tend to decrease both in absolute magnitude and also in relative significance from a radio propagation point of view.

Two basic types of data are taken as the measurement team moves along each walking radial. One type is referred to as the "primary walking data," and the other is referred to as "supplementary walking data." The primary data consists of a measurement of the maximum and minimum fields within the vicinity of each measurement point.

Table 4.1

COMPARISON BETWEEN NOMINAL AND ACTUAL TRAIL DISTANCE

Point	Nominal Distance (ft)	Radial	Actual LOS Distance (ft)			
			H_t=120'	H_t=80'	H_t=40'	H_t=13'
0.5	50	W	124.2	88.9	59.9	-
		X	120.1	83.0	50.7	-
		Y	122.7	86.7	56.6	-
		Z	135.3	103.8	80.4	-
1.0	100	W	149.5	121.7	102.5	50.5
		X	142.5	113.0	92.0	50.5
		Y	146.8	118.5	98.6	50.5
		Z	167.6	143.4	127.4	50.5
1.5	150	W	185.1	163.5	149.7	100.2
		X	176.6	153.8	139.1	100.2
		Y	181.9	159.9	145.7	100.2
		Z	207.0	188.0	176.1	100.2
2.0	200	W	226.2	208.9	198.3	150.2
		X	217.0	198.9	187.7	150.2
		Y	222.7	205.1	194.3	150.2
		Z	226.2	208.9	198.3	150.2
2.5	250	W	270.3	256.0	247.4	200.1
		X	260.7	245.9	236.9	200.1
		Y	266.7	252.2	243.5	200.1
		Z	295.7	282.7	274.9	200.1
3.0	300	W	316.2	304.0	296.9	250.1
		X	306.4	293.8	286.4	250.1
		Y	312.5	300.2	292.9	250.1
		Z	342.3	331.2	324.6	250.1
10.0	1000	W	1000.8	997.1	994.9	950.0
		X	990.6	986.8	984.6	950.0
		Y	996.9	993.2	991.0	950.0
		Z	1029.1	1025.5	1023.4	950.0
49.0	4900	W	4895.4	4894.7	4894.2	4850.0
		X	4885.2	4884.5	4884.0	4850.0
		Y	4891.6	4890.8	4890.3	4850.0
		Z	4924.1	4923.3	4922.9	4850.0
74.0	7400	W	7395.0	7394.5	7394.2	7350.0
		X	7384.8	7384.3	7384.0	7350.0
		Y	7391.1	7390.6	7390.3	7350.0
		Z	7423.6	7423.1	7422.9	7350.0

The receiving antenna is kept at a height of 6 feet while being moved along the trail a distance of about ±6 feet for the near points and a distance of about ±10 feet for the more distant points. For the shorter wavelengths (e.g., 25 Mc/s) this excursion is not usually enough to define a complete change from maximum to minimum, but does realistically represent the change in field over a relatively large sampling area. On the other hand, at the very short wavelengths (e.g., 250 Mc/s) the field may behave erratically for very slight changes in antenna position. In these cases, five spot readings are taken at random locations within the vicinity of each measurement point.

The supplementary walking data is taken at field points 2, 10, 25, 49 and 74 along each walking radial. The supplemental measurements consist of (1) measurements of the received field as the receiving antenna is raised in height by 2-foot intervals from zero to 10 feet, (2) a measurement of the received field when the receiving antenna is oriented in a polarization opposite to that of the transmitting antenna, and (3) a measurement of the received field for different antenna orientations.

Figure 4.3 provides an example of a primary walking data sheet which has been filled out by the measurement team in Thailand. Figure 4.4 is an example of a corresponding supplementary walking data sheet.

For each measurement, a meter reading, M, and an attenuator setting, A, are recorded. The meter reading varies from zero to 20 dB and is read to the nearest dB. The attenuator reading typically varies from zero to 100 dB in 20-dB steps. Additional parameters are recorded as follows.

FIELD DATA

WALKING MEASUREMENTS

REF. NO. YZ

Freq. - Pol. - Ht. 100 H 120

Date 25 Nov. 66 Radial Y Personnel RAGAN & CONWAY

Equipment: Rx. Smith S/N 121 Rx. Cable 11 Other (Cal - 72.8 Begin) (Cal 72.7 End)

Rx. Antenna Factor + Cable Loss 7.8+0.8 db.

Time	Point	Attenuation + Meter Reading (db/uv) Max.	Min.	1	2	3	4	5	Rad. Power (dbm)
0955	0.5	100+13	100+3						+43.9
	1.0	100+3	80+15						
1001	1.5	100+7	100+1						
	2.0	100+9	100+7						
	2.5	100+3	100+1						
	"	100+1	80+19						
	3.5	100+1	80+18						
1031	4.0	80+17	80+12						
	4.5	80+15	80+9						
	5.0	80+12	80+17						
	5.5	80+7	80+3						
1035	6.0	80+12	80+9						
	6.5	80+9	80+5						
	7.0	80+2	60+15						
	7.5	60+16	60+5						
1040	8.0	60+17	60+9						
	8.5	80+5	80+1						
	9.0	80+3	60+18						
	9.5	60+19	60+15						
	10.0	60+11	60+7						
	11.0	60+14	60+12						
	12.0	60+19	60+13						
1052	13.0	60+12	60+10						
	14.0	60+8	60-1						
	15	80+2	40+3	40+18	40+14	40+19	40+2	60+2	(sharp null)
1106	16.0	60+11	60+8						
	17.0	60+6	60-1						
	18.0	60+6	60+3						
	19.0	60+4	40+18						
1112	20.0	60+8	60+5						
	21.0	40+20	40+8	smooth	variation				
	22.0	40+18	40+9						
	23	40+16	40+7						
	24	40+19	40+17						
	25	40+17	40+11						
1132	27	40+6	20+12	40+1	20+17	40+2	40+5	20+12	
	29	40+9	40+1						
	31	40+5	20+6	20+19	20+13	20+19	20+15	20+12	
	33	40+8	20+14	20+19	40+3	20+14	40+7	20+17	
1147	35	40+11	40+0						+43.7
	37	40+4	20+6	20+11	40+1	20+17	20+~~12~~	20+18	
	39	40+4	20+18						
1151	41	40+4	20+14						
1200	43.	40+2	20+8						+43.9
	45	40+6	20+10						
	47	40+6	40+0						
1209	49	40+4	20-1	20+19	40+5	20+17	20+19	20+1	
	54	40+2	20+18						
1222	59	40+5	40+1						
1333	64	40+8	20+16	(smooth	variation)				+44.0
1337	69	20+20	20+6		"	"			
1341	74	20+19	20+12						

Figure 4.3 Field Sheet for Primary Walking Data

SUPPLIMENTARY FIELD DATA

WALKING MEASUREMENTS

REF. NO. YZ

Date 25 Nov 66 Freq. -Pol. -Ht. 100 H 120 Radial Y

Time	Point	Attenuator setting + meter reading (db/uv) h=0'	h=2'	h=4'	h=6'	h=8'	h=10'	VERT h=6'
1022	2.0	80+3	100+3	100+7	100+8	100+5	80+10	
1050	10	20+17	40+17	60+3	60+8	60+10	60+11	
1126	25	20+19	40+10	40+12	40+13	40+14	40+16	
1210	49	20+4	20+20	40+3	40+5	40+2	40+3	
1247	74	0+6	20+5	20+11	20+16	20+16	20+15	20+0

Time	Point	Attenuator set + meter rdng. (db/uv) 0°	+45°	-45°	90°
1025	20	100+8	100+5	100+4	80+16
1050	10.	60+8	60+4	60+5	40+19
1127	25	40+13	40+7	40+14	40+9
1210	49	40+4	40+3	40+3	20+13
1247	74	20+17	20+1[illegible]	20+15	20+4

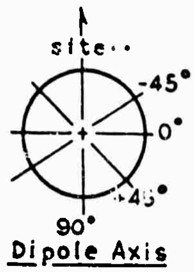

Figure 4.4 Field Sheet for Supplementary Walking Data

1. Power input to the transmitting antenna, P, in dBm

2. Receiving antenna factor, AF, in dB

3. Cable loss at the receiving antenna, C, in dB

4. Measurement point at which the measurement was taken

5. Approximate local time of the measurement

6. Date

7. Radial designation

8. Names of the measurement engineers

9. Name of the meter used

10. Identification of the cable used

11. Frequency in Mc/s, polarization, and transmitting antenna height used

12. Data reference number which provides a unique identification for each data set

13. Reading of the noise level whenever a data point is close to the noise

Figure 4.3 shows that only maximum and minimum readings were taken at measurement points 0.5 through 14.0. This means that the received field varied relatively smoothly as the receiving antenna was moved and that well-defined maximum and minimum readings were observed in the field. The notation "smooth variation" beside the measurement taken at point 21.0 indicates that the field variation was relatively smooth, but that a distinct maximum and minimum could not be established.

Measurement points 15.0, 27.0, 31.0, 33.0, 37.0, and 49.0 are typical of situations in which a maximum and a minimum reading were attempted, but the field variation was quite erratic. Therefore, five random samplings near each point are also provided.

The data from Figures 4.3 and 4.4 is converted to measured field strength, E_{meas}, by means of equation 1.

$$20 \log_{10} E_{meas} = M + A + AF + C \qquad (1)$$

where

E_{meas} = field strength in μv/m

M = meter reading in dB

A = attenuator setting in dB

AF = antenna factor in dB, that relates incident field strength to antenna terminal voltage

C = loss in dB of cable connecting antenna to meter

The measured field, E_{meas}, is then converted to basic transmission loss, L_b, by means of equation 2.

$$L_b = 36.57 + 20 \log f + 20 \log E_1 - 20 \log E_{meas} \qquad (2)$$

where

L_b = basic transmission loss in dB

f = frequency in megacycles/second

E_1 = unattenuated field strength in μv/m expected from the transmitting system at 1 mile

E_{meas} = any measured value of field strength produced as a result of radiation from the transmitting system used to determine E_1 above

The transmitting antennas which have been used so far for the walking measurements at Songkhla in the frequency range from 25 Mc/s to 250 Mc/s, for both horizontal and vertical polarizations, have been elevated half-wave dipoles. The horizontal dipoles have been oriented broadside to the radial along which measurements are being made. The expression which is used to determine 20 log E_1 for these antennas is given in equation 3.

$$20 \log E_1 = 72.7 + 10 \log P \tag{3}$$

where

P = power delivered to the antenna in watts

Measured field data from the field team's data recording forms is converted to punched cards at the Principal Laboratories. A digital computer is then used to order the data and to convert it to units of basic transmission loss. Figure 4.5 is an example of initial computer output for the primary walking data shown in Figure 4.3. The sequence number is a unique sorting code used by the computer to sort the data in various ways. The reference number, date, frequency, transmitting antenna height, and polarization are taken from the data provided at the top of each field data sheet. The four columns of data correspond to the nominal distance to the measurement point, the measurement point number and the minimum and maximum propagation loss. The minimum propagation loss corresponds to the maximum measured field strength, and the maximum propagation loss corresponds to the minimum measured field strength. The radial on which the data was taken is included as part of the data reference number.

SEQ.NO.	REF.NO.	DATE	FREQ(MC)	HT(FT)	POL.	DIST(FT)	POINT	MAX LB	MIN LB
167	Y 2	11 25 66	100.000	120	H				
						45.3	0.5	54.7	41.7
						92.6	1.0	59.7	51.7
						141.7	1.5	53.7	47.7
						191.3	2.0	47.7	45.7
						241.1	2.5	53.7	51.7
						290.9	3.0	55.7	53.7
						340.8	3.5	56.7	53.7
						390.7	4.0	62.7	57.7
						440.7	4.5	65.7	59.7
						490.6	5.0	62.7	57.7
						540.6	5.5	71.7	67.7
						590.6	6.0	65.7	62.7
						640.5	6.5	69.7	65.7
						690.5	7.0	79.7	72.7
						740.5	7.5	89.7	78.7
						790.5	8.0	85.7	77.7
						840.4	8.5	73.7	69.7
						890.4	9.0	76.7	71.7
						940.4	9.5	79.7	75.7
						990.4	10.0	87.7	83.7
						1090.4	11.0	82.7	80.7
						1190.4	12.0	81.7	75.7
						1290.4	13.0	84.7	82.7
						1390.3	14.0	93.7	86.7
						1490.3	15.0	112.7	92.7
						1590.3	16.0	86.7	[illegible]
						1690.3	17.0	93.7	88.7
						1790.3	18.0	91.7	88.7
						1890.3	19.0	96.7	90.7
						1990.3	20.0	89.7	86.7
						2090.3	21.0	106.7	94.7
						2190.3	22.0	105.7	95.7
						2290.3	23.0	107.7	95.7
						2390.3	24.0	97.7	95.7
						2490.3	25.0	103.7	97.7
						2690.3	27.0	122.7	108.7
						2890.3	29.0	113.7	105.7
						3090.3	31.0	122.7	109.7
						3290.3	33.0	120.7	106.7
						3490.2	35.0	114.5	103.5
						3690.2	37.0	132.5	110.5
						3890.2	39.0	116.5	110.5
						4090.2	41.0	120.5	110.5
						4290.2	43.0	126.7	112.7
						4490.2	45.0	124.7	108.7
						4690.2	47.0	114.7	108.7
						4890.2	49.0	133.7	109.7
						5390.2	54.0	116.7	112.7
						5890.2	59.0	113.7	109.7
						6390.2	64.0	118.8	106.8
						6890.2	69.0	128.8	114.8
						7390.2	74.0	122.8	115.8

Figure 4.5 Computer Printout of Walking Data

An asterisk beside a value of propagation loss means that the noise was within 6 dB of the measured field strength and that a noise correction was made to the measured value. If the noise is greater than or equal to the measurement, no noise correction is attempted and the transmission loss is set to zero, indicating that the value is not to be used.

Figures 4.6 through 4.20 provide examples of converted walking data. The top curve on each figure corresponds to the minimum propagation loss as a function of distance, and the next curve down corresponds to the maximum propagation loss. The curve at the bottom of each graph indicates the terrain height along the radial (not including foliage) relative to the terrain height at the transmitting location. The terrain heights were surveyed by transit. Figures 4.6, 4.7, and 4.8 are the first three sets of 50-Mc/s data received from Thailand. Figures 4.9 through 4.20 show path loss at all transmitting antenna heights (13, 40, 80, and 120 feet) along radials X, Y, and Z.

The following systematic method is used to identify various sets and families of curves such as those shown in Figure 4.6.

$$L_b = F(f, H_t, P, d, H_r)$$

The above format, which is used to identify each L_b graph, relates the basic transmission loss (L_b) derived from measurements to five basic variables: frequency, in megacycles, f; transmitting antenna height, in feet, H_t;

polarization, horizontal or vertical, P; distance in feet or miles, d; and receiving antenna height, in feet, H_r. The identification used on Figure 4.6 is

$$L_b = F_X(50, 13, H, d, 6.0) \text{ X-5}$$

This identification indicates that the distance was varied while the other four variables remained fixed at the values indicated. The subscript "X" denotes the fact that the measurements were taken along trail X. The letter and number (such as "X-5" on Figure 4.6), which follow the matrix identifying the test parameters, are the reference number of the data sheets from which the particular figure was derived.

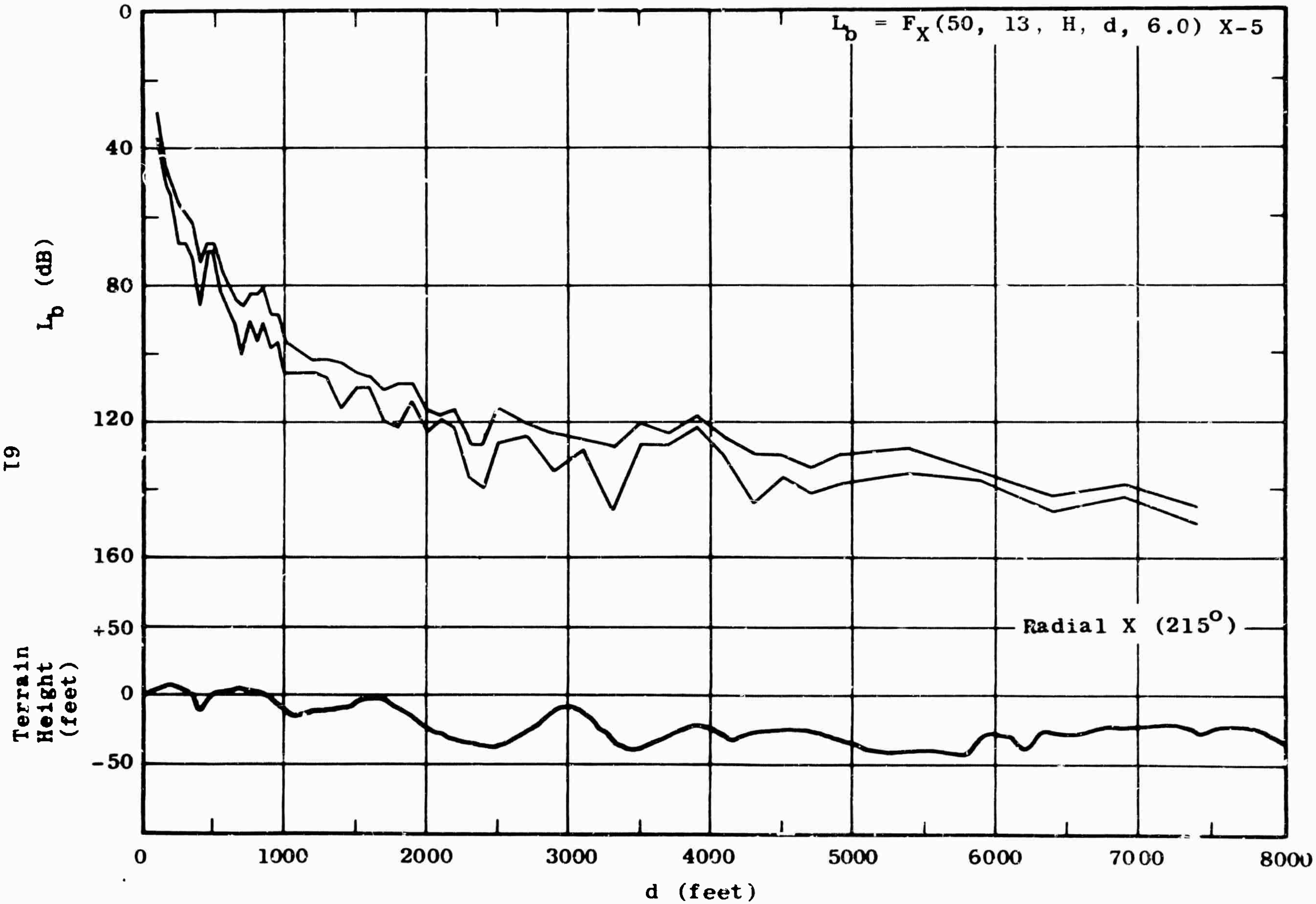

Figure 4.6 Maximum and Minimum Basic Transmission Loss as a Function of Distance

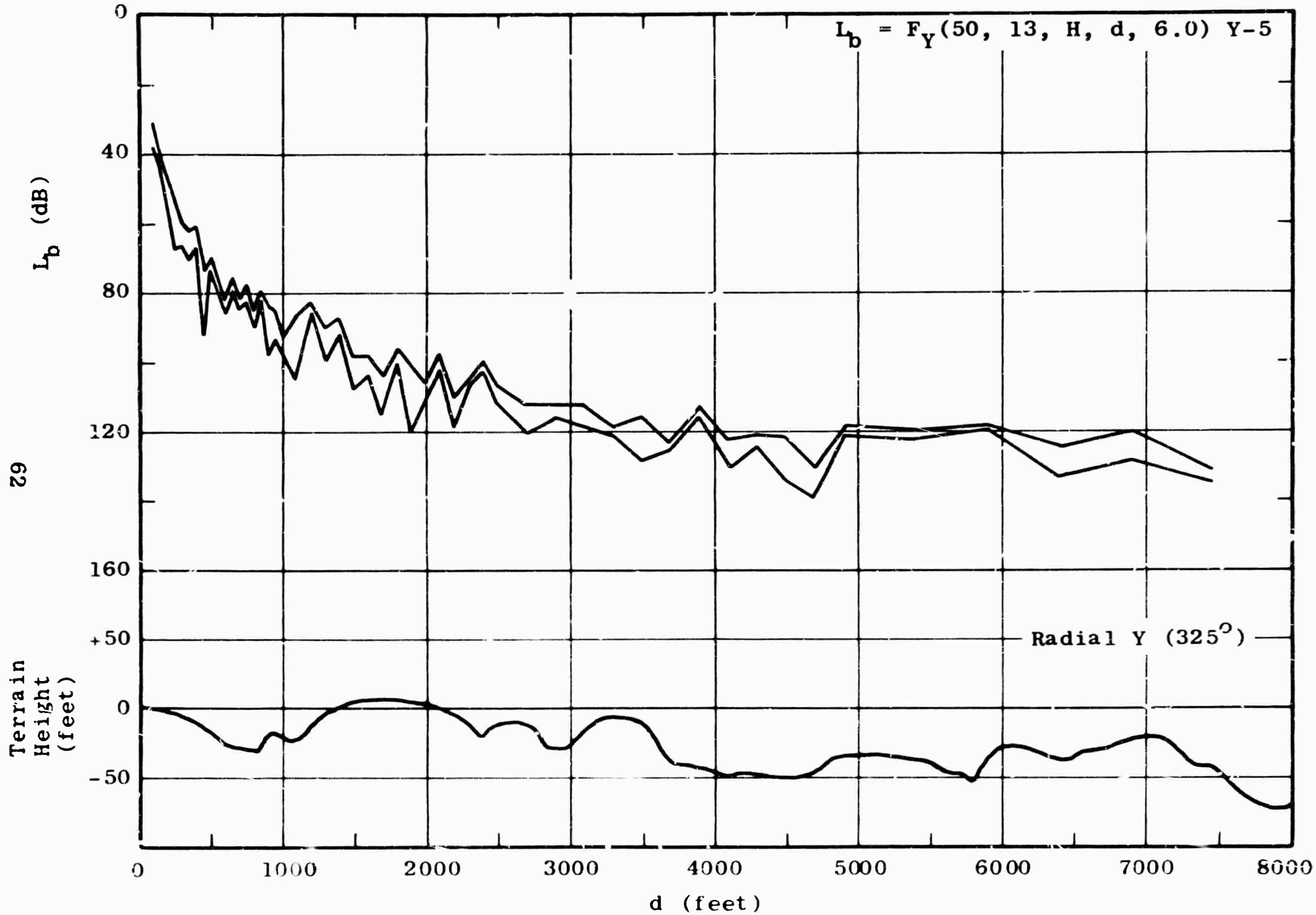

Figure 4.7 Maximum and Minimum Basic Transmission Loss as a Function of Distance

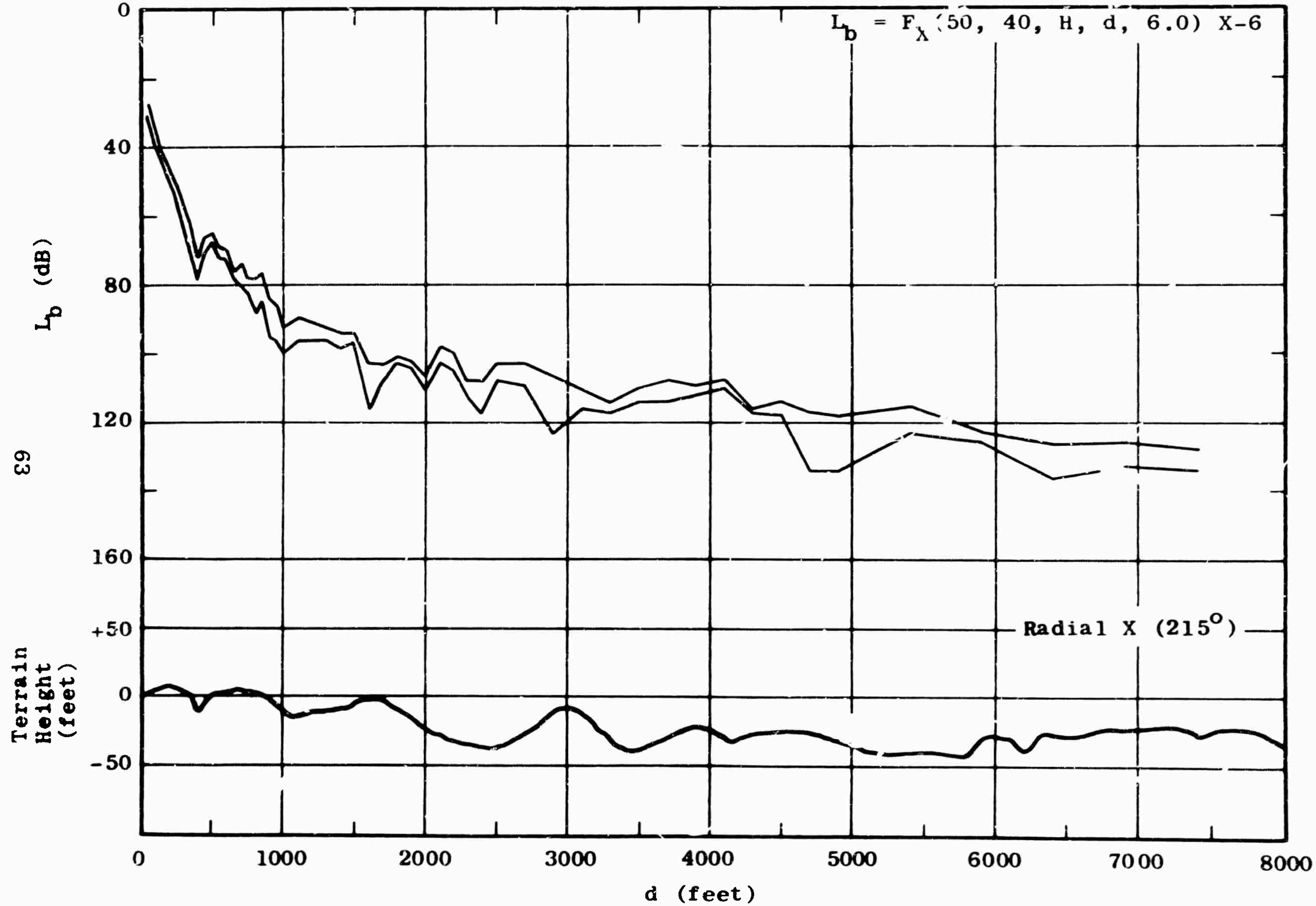

Figure 4.8 Maximum and Minimum Basic Transmission Loss as a Function of Distance

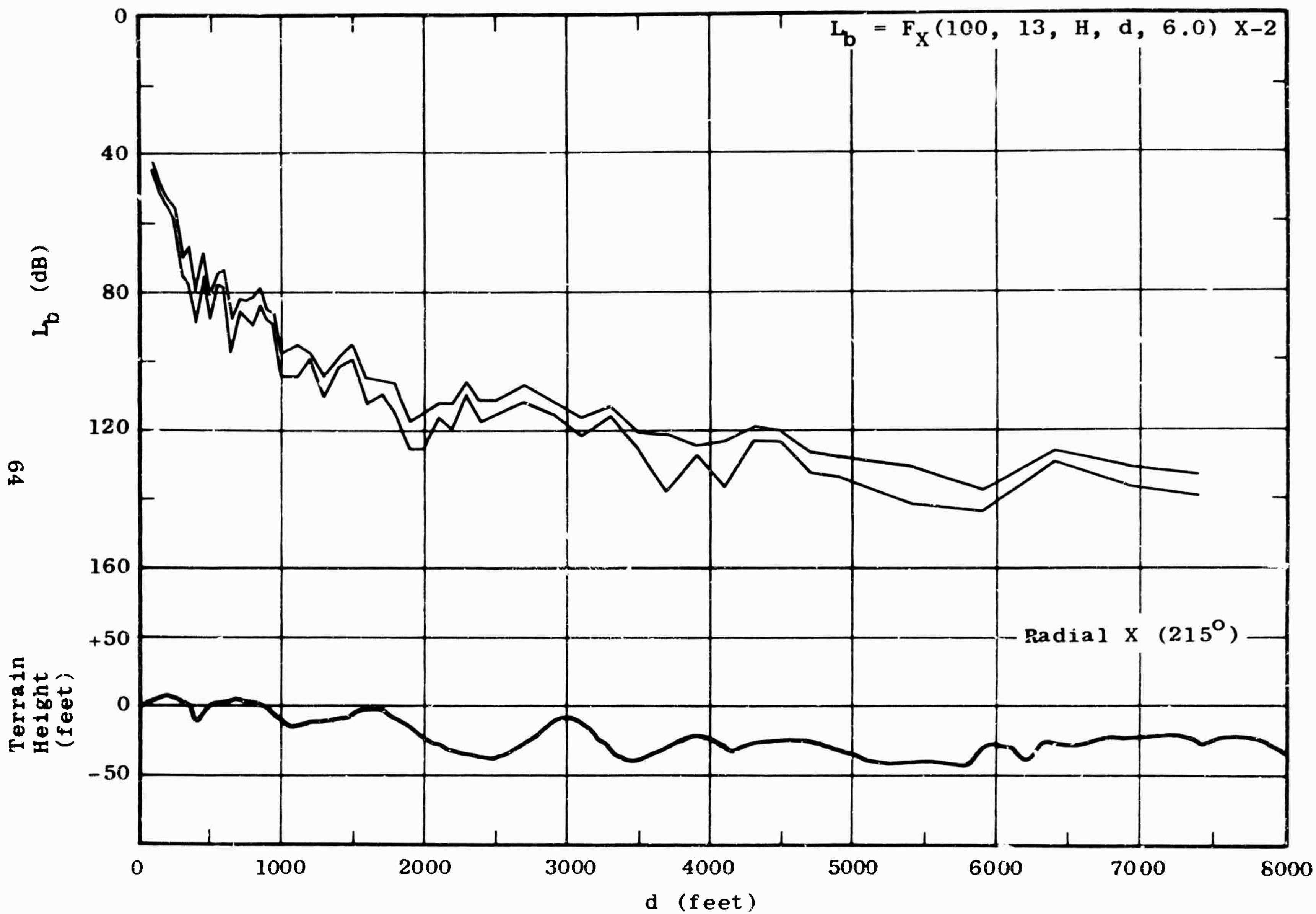

Figure 4.9 Maximum and Minimum Basic Transmission Loss as a Function of Distance

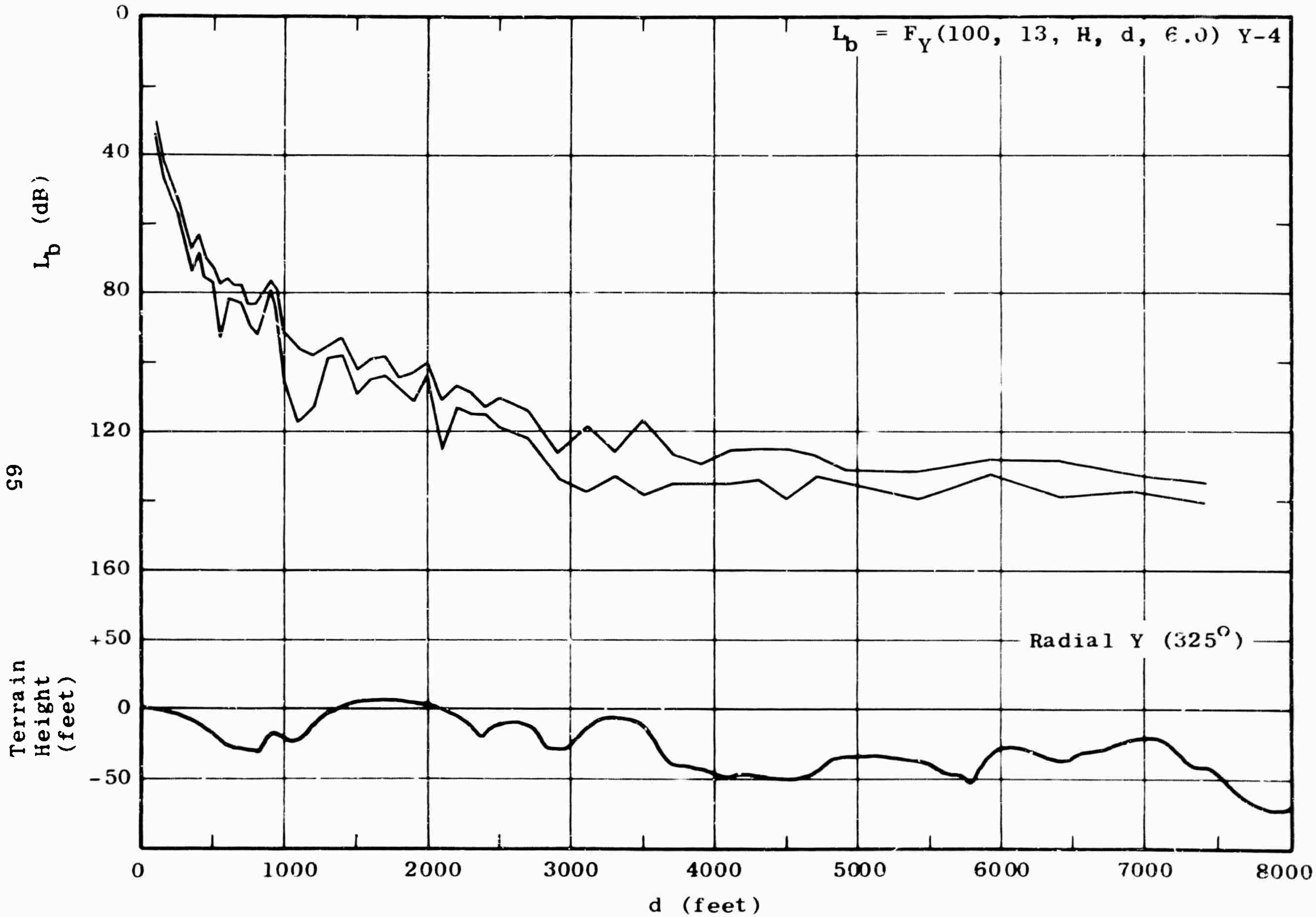

Figure 4.10 Maximum and Minimum Basic Transmission Loss as a Function of Distance

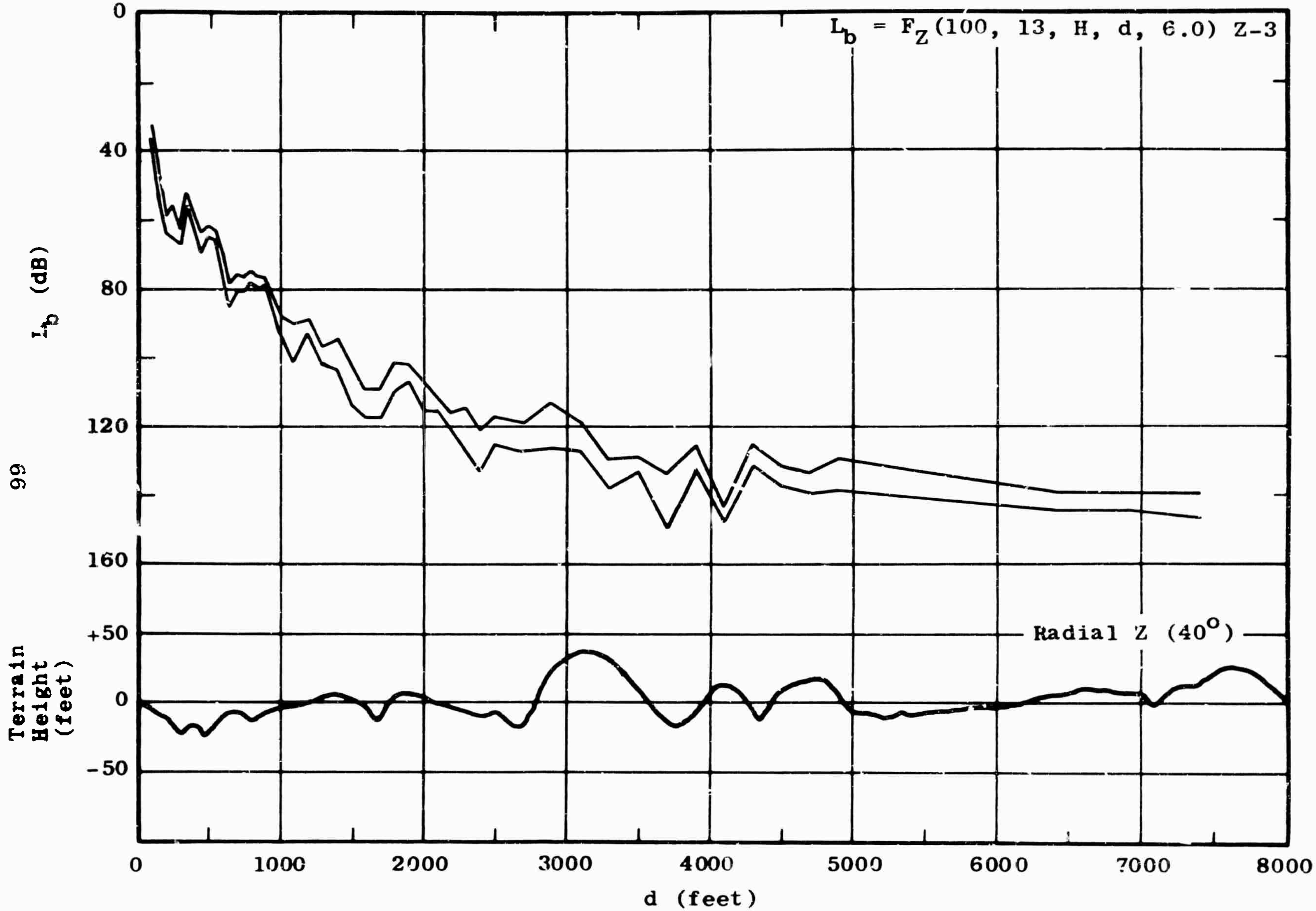

Figure 4.11 Maximum and Minimum Basic Transmission Loss as a Function of Distance

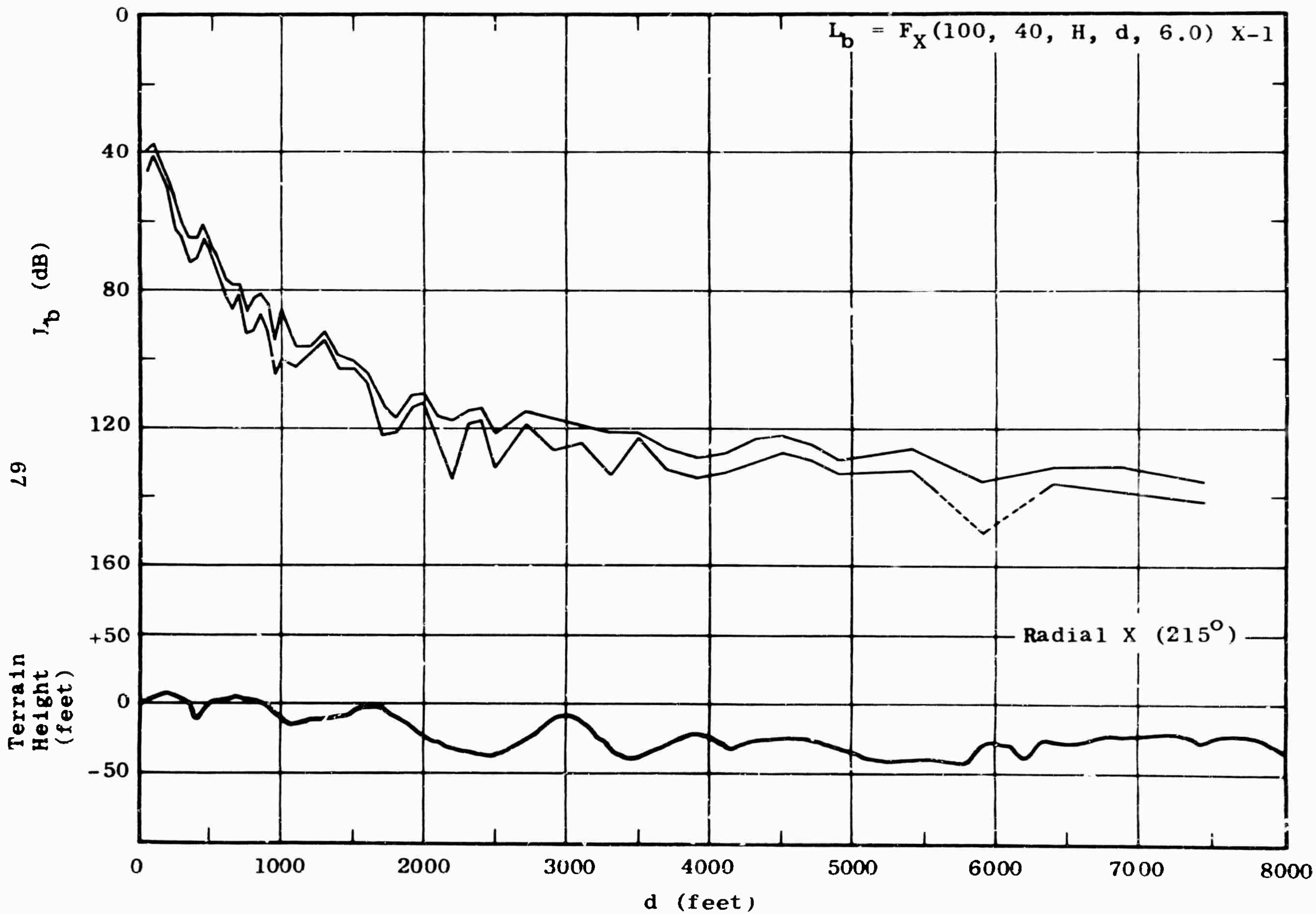

Figure 4.12 Maximum and Minimum Basic Transmission Loss as a Function of Distance

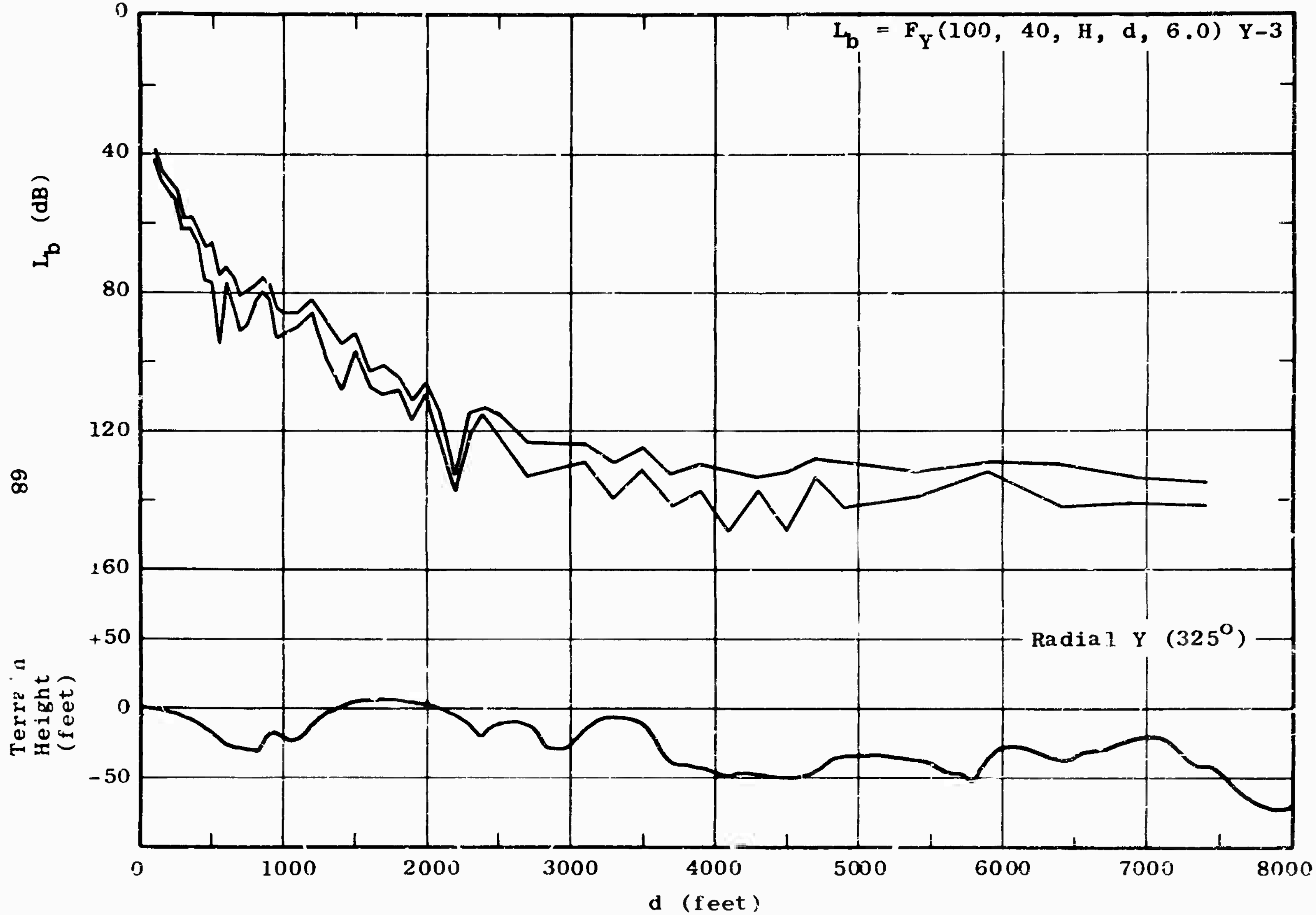

Figure 4.13 Maximum and Minimum Basic Transmission Loss as a Function of Distance

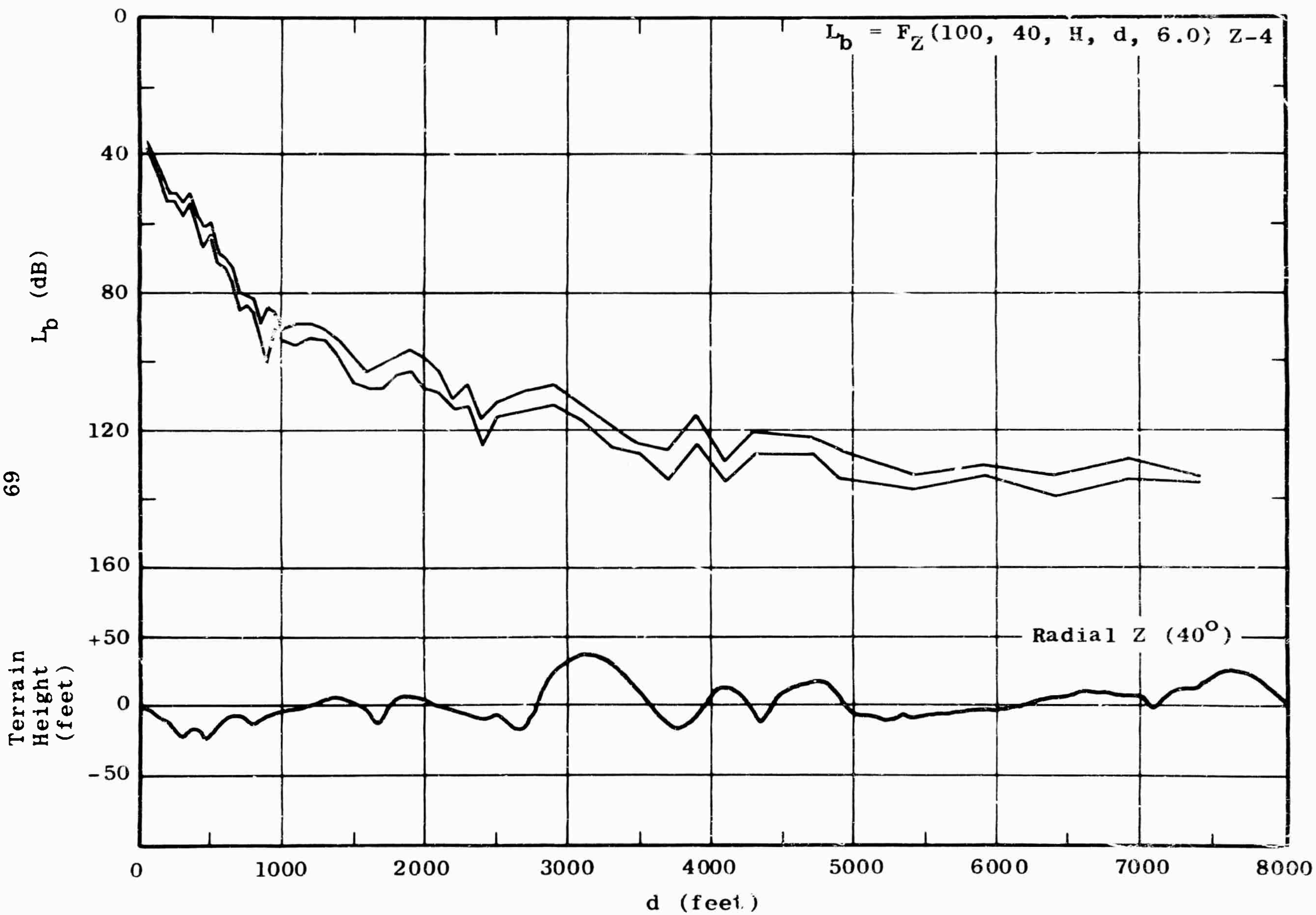

Figure 4.14 Maximum and Minimum Basic Transmission Loss as a Function of Distance

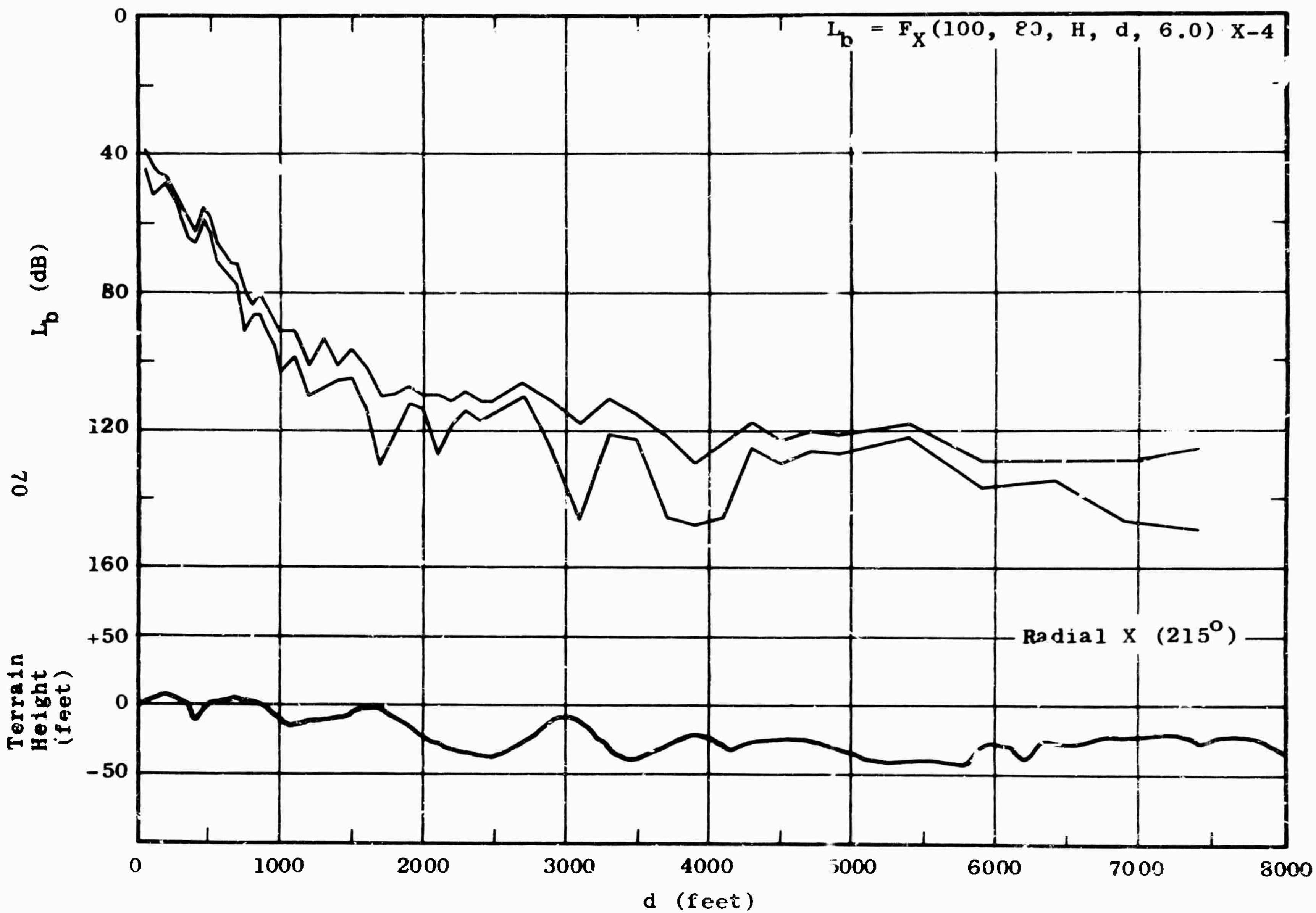

Figure 4.15 Maximum and Minimum Basic Transmission Loss as a Function of Distance

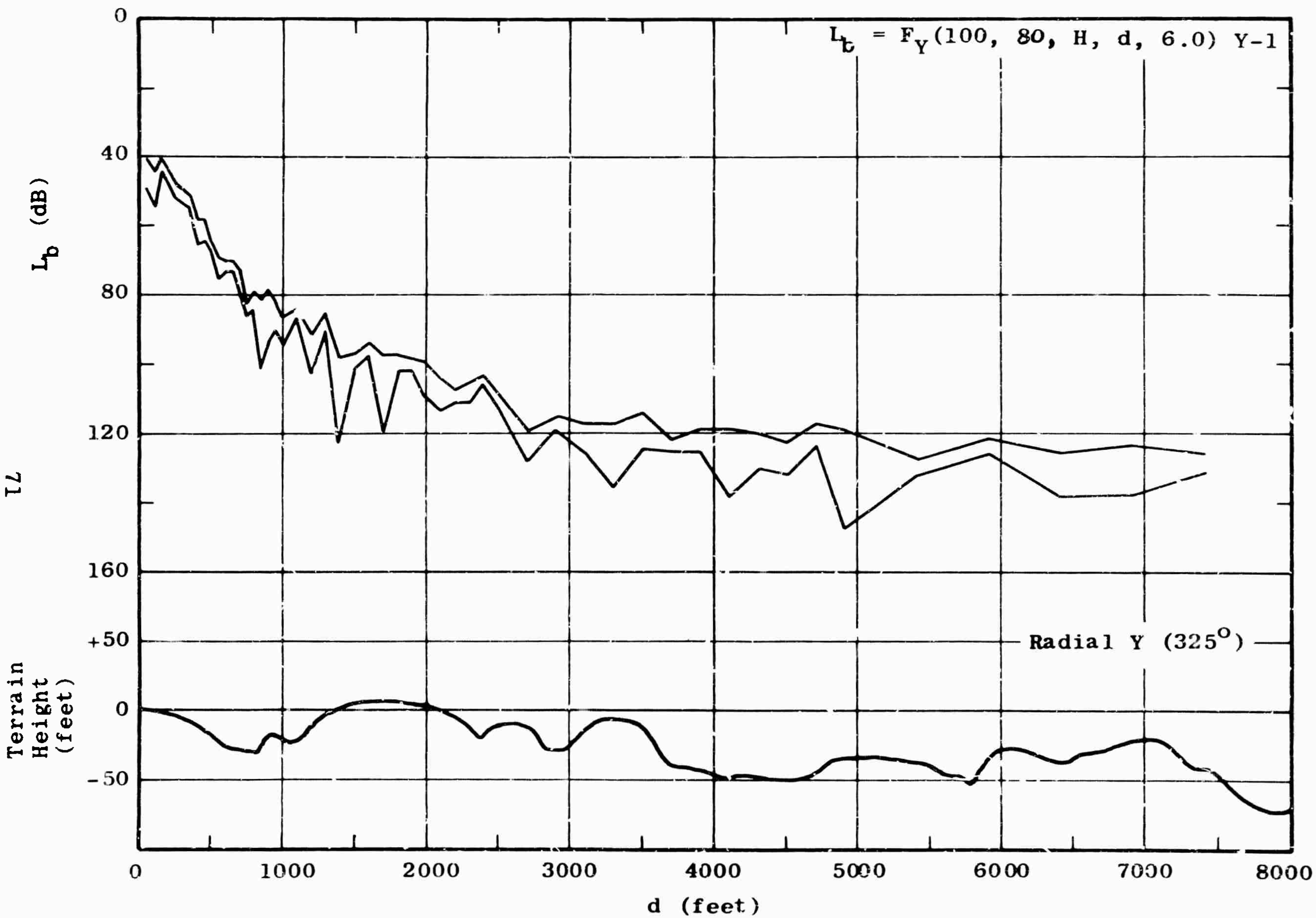

Figure 4.16 Maximum and Minimum Basic Transmission Loss as a Function of Distance

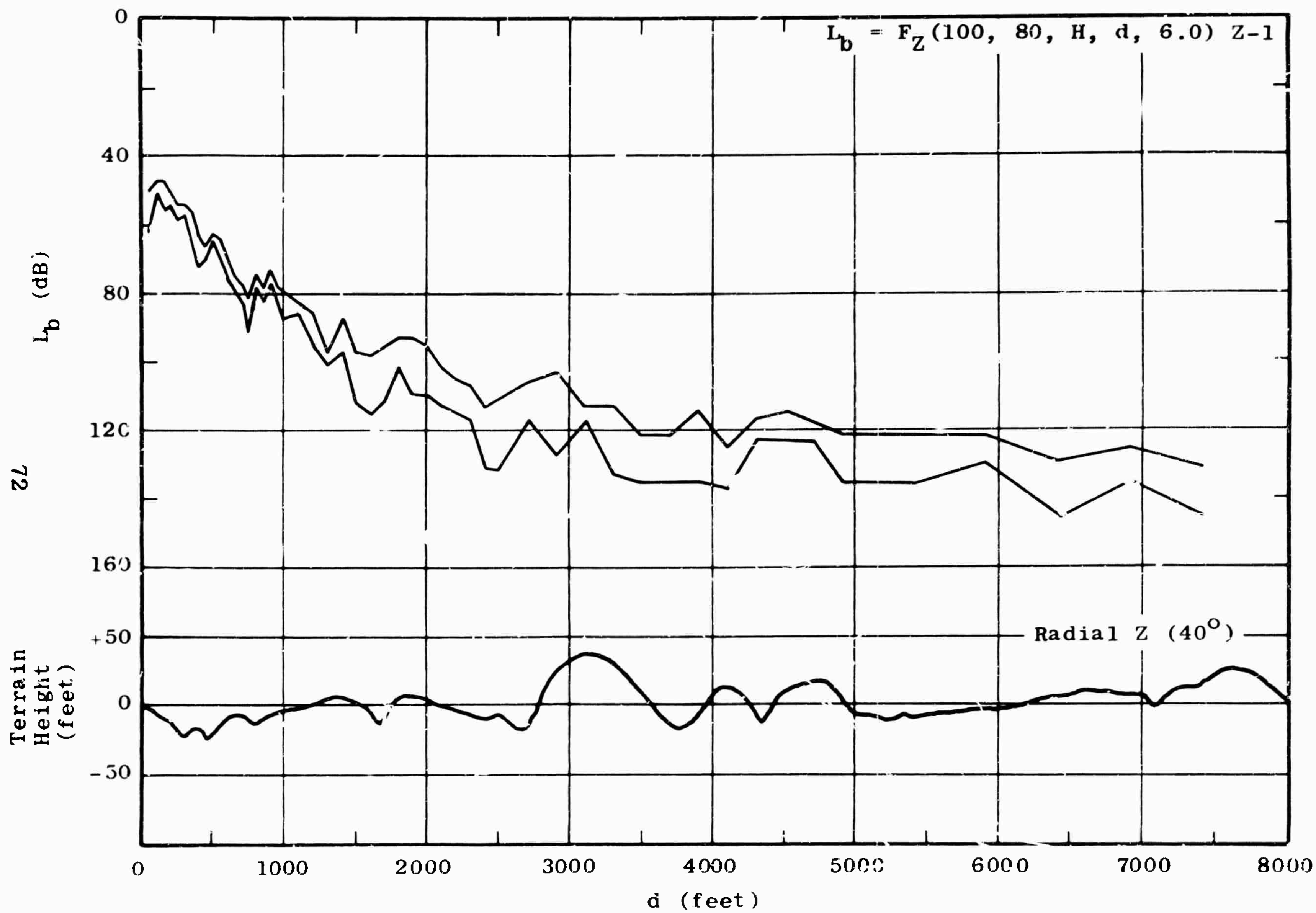

Figure 4.17 Maximum and Minimum Basic Transmission Loss as a Function of Distance

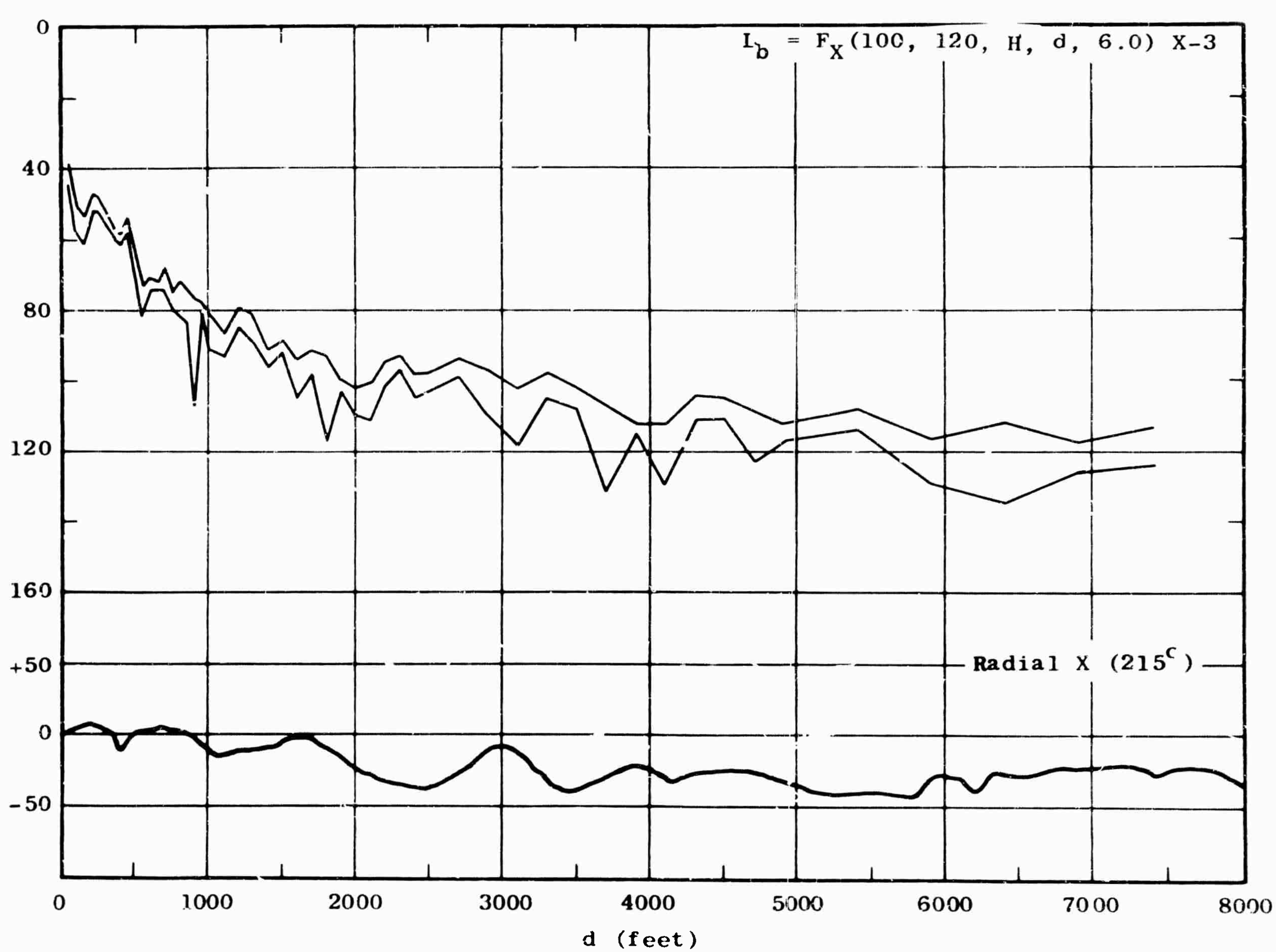

Figure 4.18 Maximum and Minimum Basic Transmission Loss as a Function of Distance

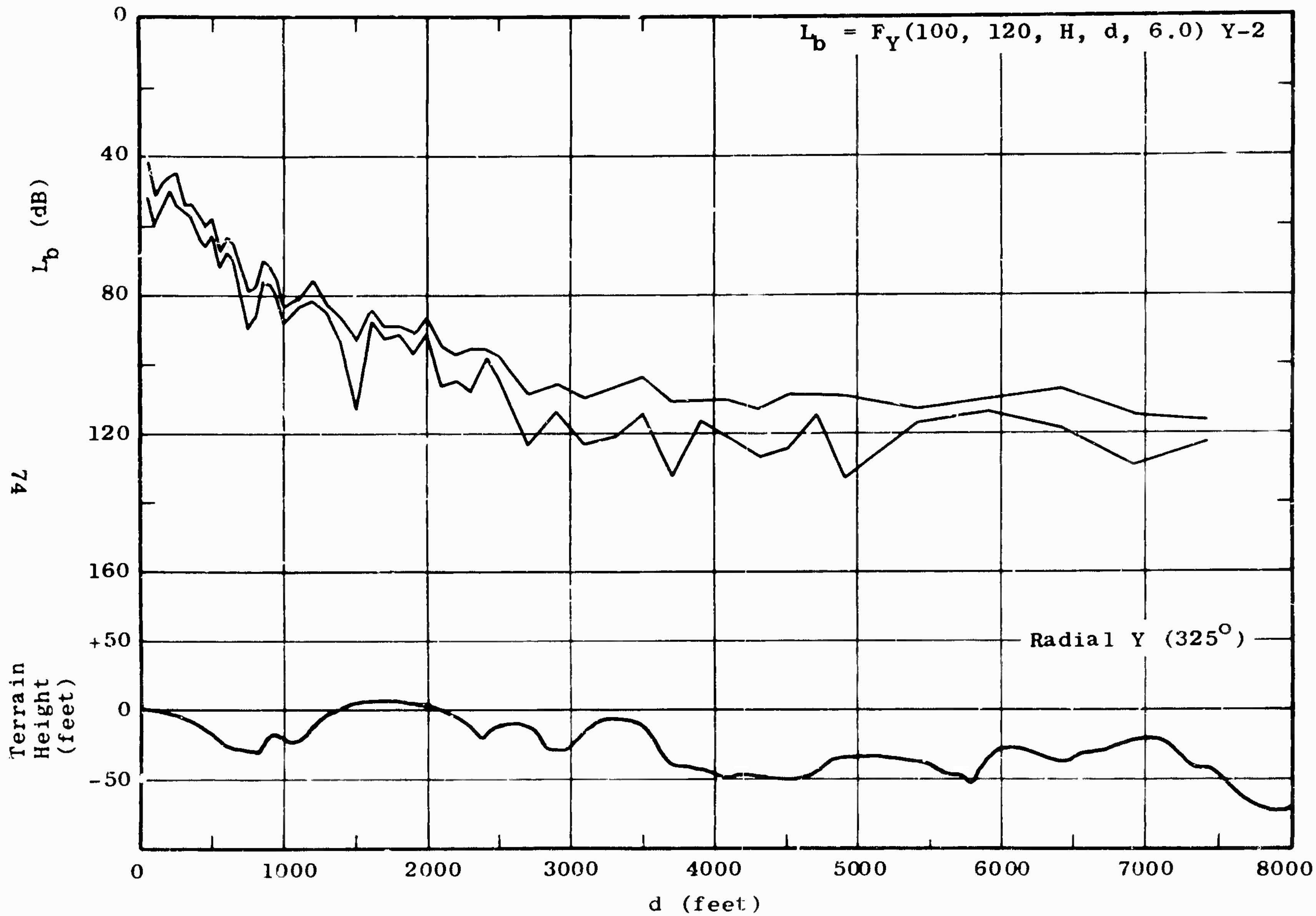

Figure 4.19 Maximum and Minimum Basic Transmission Loss as a Function of Distance

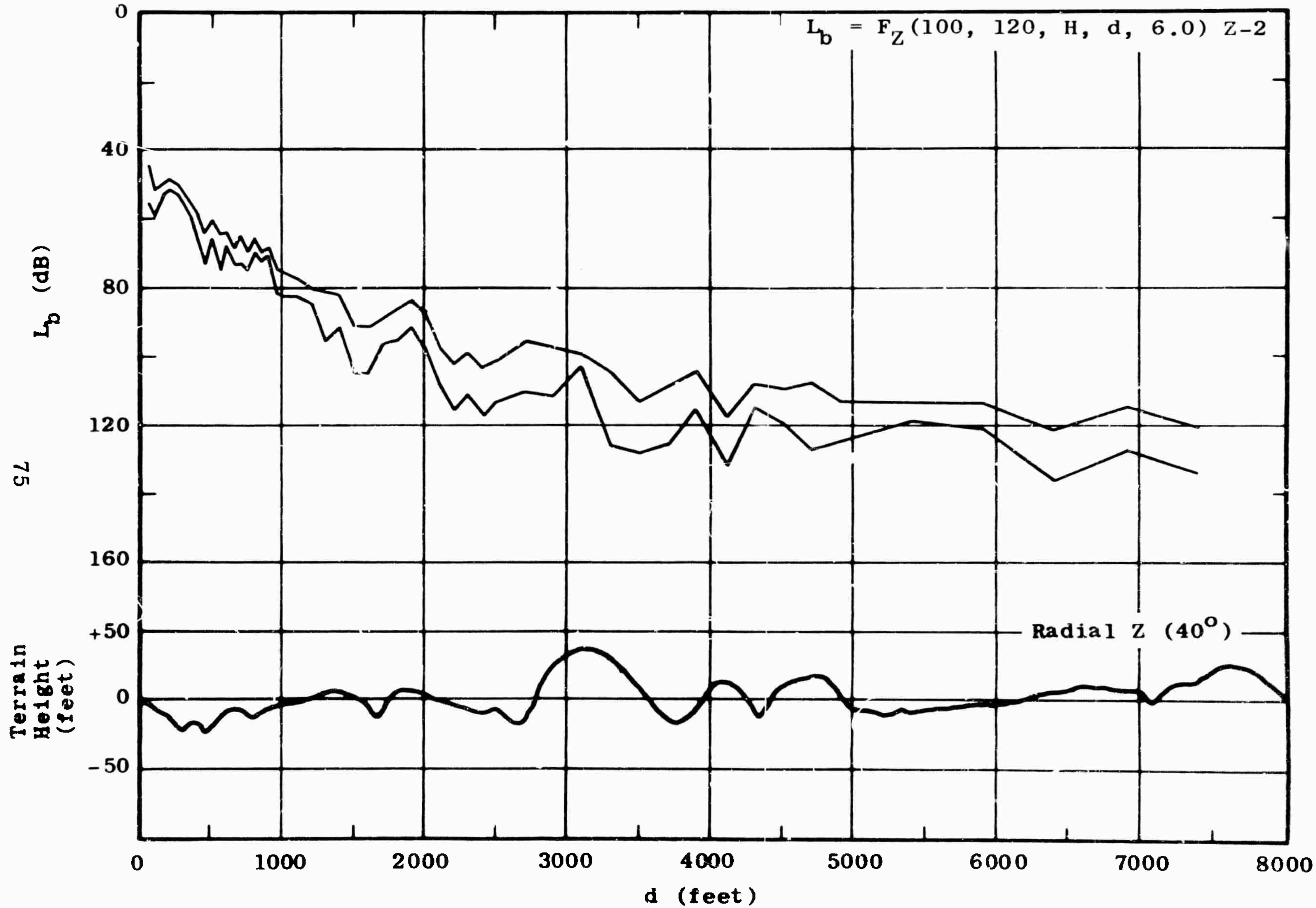

Figure 4.20 Maximum and Minimum Basic Transmission Loss as a Function of Distance

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5. INSTRUMENTATION

The logistics of the Songkhla test program have dictated many aspects of the testing itself, including the choice of instruments. Whereas the existence of cart trails in the Pak Chong area led to the development of measurement techniques using equipment to be carried by vehicle, the lack of these trails at Songkhla has led to the development of hand carried and helicopter transported measuring equipment. Since the helicopter used at Songkhla is essentially able to carry all the equipment that was carried by vehicle at Pak Chong, no significant changes have had to be made in this category of equipment.

However, there have been important changes made in the hand carried equipment needed for the short-range measurements. These changes, which have meant modifying equipment on hand and acquiring different equipment, have been made necessary by the increased attention focused on short-range, low-antenna-height tests and by the desirability of measuring this phenomena at Songkhla with hand carried or "man-pack" equipment.

Another necessary change in equipment was the lengthening of the antenna masts designed for Pak Chong, so that they would reach above the jungle foliage at Songkhla.

In other respects the test equipment inventory is not substantially different from what it was at Pak Chong. Similar test antennas and transmitters are being used. Likewise, the equipment for tests in the 550-Mc/s to 10-Gc/s range is like that used at Pak Chong, except where certain items have been dropped because the tests for which they were intended will not be repeated at Songkhla.

Those pieces of equipment which have been detailed in earlier reports will be listed and briefly described here; new and modified equipment will be covered in greater detail.

5.1 Field Strength Meters

The test frequencies in the Songkhla test program range from 880 kc/s to 10 Gc/s. A combination of four field intensity meters will be used to cover different frequency ranges and test conditions. The field intensity meters which are used below 550 Mc/s must be capable of being carried by hand, for they will be used on the foot path radial trails, along which the short-range measurements will be made. Meters which meet the requirements of portability, durability, and sensitivity are the RCA WX2-E, the Smith SM-1, and the Astro SR-209-6. Above 550 Mc/s, the testing will involve highly directional antennas that are rigidly coupled to antenna towers and positions. At these frequencies, portability is a negligible consideration, and the Singer-Metrics NF-112 will be adequate. Table 5.1 summarizes the pertinent characteristics of these meters.

Table 5.1

SPECIFICATIONS OF FIELD INTENSITY METERS

Model	Frequency Range	Maximum Sensitivity
RCA WX2-E	540 kc/s - 1600 kc/s	10 μv/m*
Smith SM-1	60 Mc/s - 250 Mc/s and	50 μv
	400 Mc/s - 850 Mc/s	50 μv
Astro SR-209-6	1.5 Mc/s - 500 Mc/s	1 μv
Singer NF-112	1.0 Gc/s - 10 Gc/s	10 μv

*Using special WX2-E test antenna

The WX2-E and the NF-112 have been used at Pak Chong and are fully described in previous reports. The Astro field intensity meter is a new meter, which is more completely described in Section 5.1.1. The Smith, though it was used at Pak Chong, has undergone some basic modifications. The purpose and nature of the modifications are covered in Section 5.1.2.

5.1.1 Astro Field Intensity Meter

The SR-209-6 is a transistorized, modular field intensity meter. In terms of circuitry, it is basically a superheterodyne receiver with two selectable IF bandwidths, 10 kc/s and 100 kc/s. A choice of six modular RF tuning heads allows it to be used from 1.5 Mc/s to 500 Mc/s. There is a modular rechargeable battery pack which fits into the meter and gives it enough power for about five or six hours of operation. A conventional power supply can also be used.

The meter is capable of responding to CW, AM, or PAM modes of operation. The range of measurable voltage (at the antenna input terminals) is from 1 microvolt rms to 5 volts rms. These voltages are registered on a panel meter reading from 0 to 20 dB. There is a 10-dB step attenuator with a total of 120 dB attenuation. There are also dc, recorder, and video outputs. With an RF tuning head and the battery pack installed, the total weight of the unit is approximately 32 pounds. Table 5.2 lists the specifications of the available RF tuning heads.

Table 5.2

TUNING HEADS FOR ACL SR-209-6

Model	Tuning Range (Mc/s)	Noise Figure (dB)
SM-102 P	1.5 - 3	6.0
SM-103 P	3 - 10	6.0
SM-104 P	8 - 32	6.0
SM-201 P	30 - 100	4.5 to 5.5
SM-202 P	90 - 300	6.5
SM-203 P	250 - 500	10.0

5.1.2 Smith SM-1 Modifications

The Smith SM-1 is a solid state portable field strength meter covering the frequency range of 60 to 250 Mc/s and 400 to 850 Mc/s. Owing to the high attenuation experienced by signals at 250 Mc/s and above, the relatively low transmitter power at these frequencies, and the desirability of using low gain antennas, it was not possible to measure path loss over sufficiently long transmission distances. Consequently, it was decided to modify the Smith SM-1 in order to increase its sensitivity, thus enabling path loss measurements to be made at greater distances.

The basic circuitry of the SM-1 comprises the VHF tuner, the IF amplifier, the detector, and the output meter. The IF amplifier provides the greater part of the amplification in the system. As normally wired, the second IF stage provides gain control. An adjustment in the detector and meter circuitry compensates for the noise and nonlinearity, which changes with each setting of the gain control. However, the combined procedure of adjusting gain and linearity makes it difficult to achieve maximum gain. Therefore, the gain control was moved to the RF amplifier where it controls the emitter voltage in the RF amplifier. Then, the IF stage was set for the maximum amount of gain that could be compensated for by the detector circuitry.

A second modification was to remove the input filters in the RF stage. These filters are designed to block image frequencies, but in doing this they also attenuate the desired frequency by about 10 dB. Since the electromagnetic environment is uncluttered around the frequencies of interest in the jungle, it was decided to remove the filter. Figure 5.1 shows the original and modified circuitry.

The combined effect of these two modifications has been to increase the meter sensitivity by 20 dB at 250 Mc/s and to decrease its noise level.

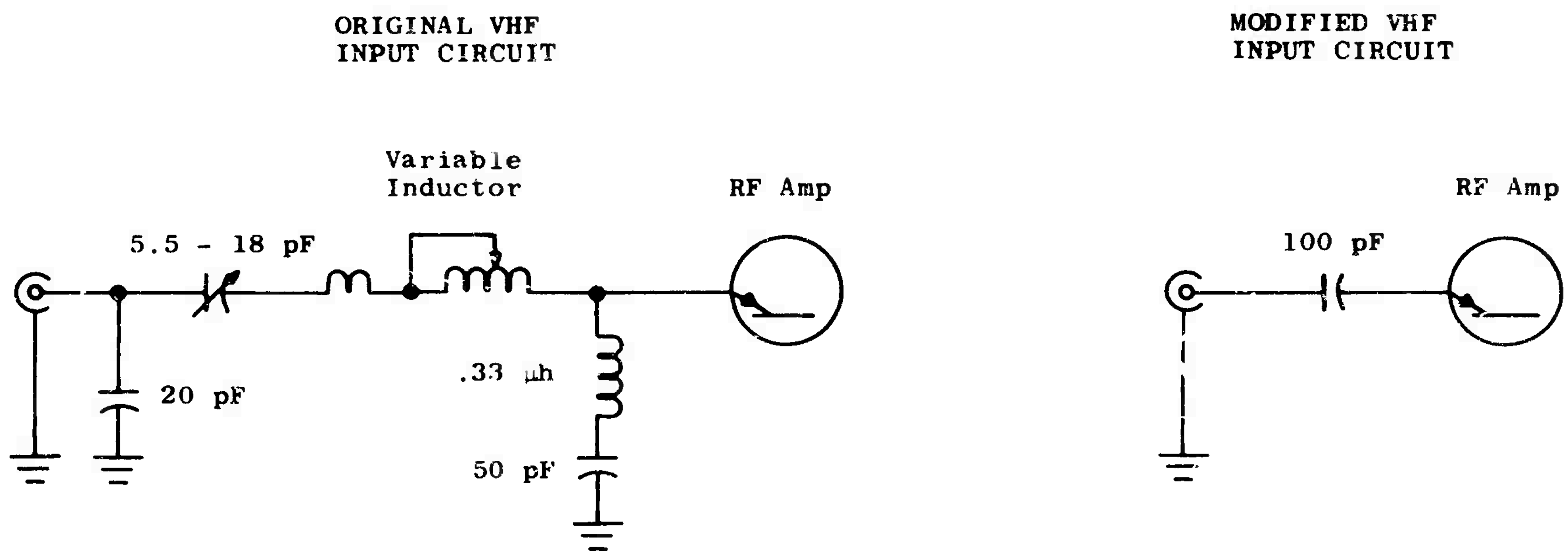

Figure 5.1 Original and Modified Input Circuitry on Smith SM-1

5.2 Test Transmitters

Military transmitters with outputs of 45 to 500 watts were used in the Pak Chong measurements over the 100-kc/s to 400-Mc/s range. Commercial signal sources and power amplifiers with outputs of from 1 to 40 watts were used for the measurements between 550 Mc/s and 10 Gc/s. This equipment proved to be satisfactory. Although some items have been in use for as long as 30 months, they have been maintained regularly and are in good condition. Test transmitters listed in Tables 5.3 and 5.4 are being used at Songkhla.

Table 5.3

880-KC/S TO 250-MC/S TEST TRANSMITTERS

Quantity	Type	Frequency (Mc/s)	Power (watts)
1	OA-232/GR	0.1 to 2	500
2	T-368/URT	1.5 to 20	500
1	AN/FRC-15	25 to 50	45
1	AN/GRC-75	50 to 100	50 to 120
1	AN/GRC-78	100 to 225	50 to 120
1	AN/GRC-81	225 to 400	50 to 120

Table 5.4

550-MC/S TO 10-GC/S TEST TRANSMITTERS

Quan.	Description	Frequency (Gc/s)	Power (watts)
1	Science Metrics ED1241 UHF Power Oscillator	0.25 to 2.5	5 to 40
1	Polarad Model 1206 Modular Microwave Signal Source	1.95 to 4.2	0.050
2	Polarad Model 1207 Modular Microwave Signal Source	3.8 to 8.2	0.050
2	Polarad Model 1208 Modular Microwave Signal Source	6.95 to 11	0.025
2	American Electronics Lab Model T601 TWT Amplifier	2 to 16	1.0

5.3 Transmitting Antennas

An insulated, vertical mast monopole with a ground radial system will be used for the 0.880-Mc/s measurements. Similar insulated vertical masts with appropriate ground radial systems will be used for vertically polarized transmissions at 2 and 12 Mc/s. Half-wave dipoles, supported by two towers, will be used for horizontal polarization in this frequency range. Half-wave dipoles, which can be operated at heights of up to 120 feet, will be used from 25 Mc/s to 500 Mc/s for vertical and horizontal polarization.

Matching networks and baluns similar to those used at Pak Chong are being used for the Songkhla operation.

Four types of antenna are used above 500 Mc/s: discone with reflector, 3-foot parabolic reflector with log-periodic feed, 18-inch parabolic reflector with horn feed, and horns. The discone-with-reflector antennas operate over the 400- to 1200-Mc/s frequency range, and the 3-foot parabolic reflector with a log-periodic feed covers the 1- to 11-Gc/s range. Available horn feed elements provide 4.19 to 10-Gc/s coverage. Presently available horn-type antennas cover the 2- to 10-Gc/s range.

The antennas are mounted on precision antenna positioners, and the complete assemblies can be elevated on guyed platform-type towers from ground level to the top of the foliage. It is also possible to rotate the antennas for vertically or horizontally polarized transmissions.

5.4 Antenna Towers

The requirements for antenna towers are set by the need to position the antennas at different heights within and above the jungle foliage. Where highly directive antennas are used (550 Mc/s and above), the towers should also rigidly support the antenna positioning system and provide a working space next to the antenna for men and equipment. The antennas used below 550 Mc/s do not need this stability or space; however, the nature of the tests at these frequencies requires the antennas to be continually raised and lowered and moved to different locations.

At both the higher and lower frequencies the towers must extend upwards about 120 feet to clear the jungle at Songkhla. Through experience gained in the Pak Chong tests, two different towers have been found to meet the requirement of the tests above and below 550 Mc/s.

The AB/216/U military tower has proven itself satisfactory on the tests above 550 Mc/s at Pak Chong. This is a guyed tower, made up of aluminum sections which are 6 feet high and approximately 6 feet wide and 4 feet deep. The units snap out into a rigid structure on the ground and are erected by stacking one unit on top of another and locking it into place. Part of the bracing of each unit is a stairway inside the tower. When guyed, these towers have the strength and stability to hold the necessary antennas, antenna positioners, test equipment, and personnel at and above the treetop level. This tower is shown in Figure 5.2.

The special, self-supporting, telescoping tubular mast that was developed for the tests below 550 Mc/s at Pak Chong will also be used at Songkhla. As originally designed, the mast had a maximum height of 80 feet. In Figure 5.3, the mast can be seen extended to its full 80-foot height, along with its erecting base and guy wires. Figure 5.4 shows the different sized tubes that make up the mast. These are fitted to one another with sleeves to construct the mast to any desired height.

Since the portability and quick assembly and adjustment that these masts offer made them ideal for the propagation tests at Pak Chong, it was desirable that they could be modified to extend an extra 40 feet to get above the Songkhla foliage. Tests showed the increase in height was possible if additional tubes of the two largest sizes were added to the mast. Thus, after the mast reaches its 80-foot design height, at which point the widest tube is being used, the next smallest tube is put below, and below that another of the largest tubes is used again.

Figure 5.2 AB/216/U Antenna Tower Located in Vegetation

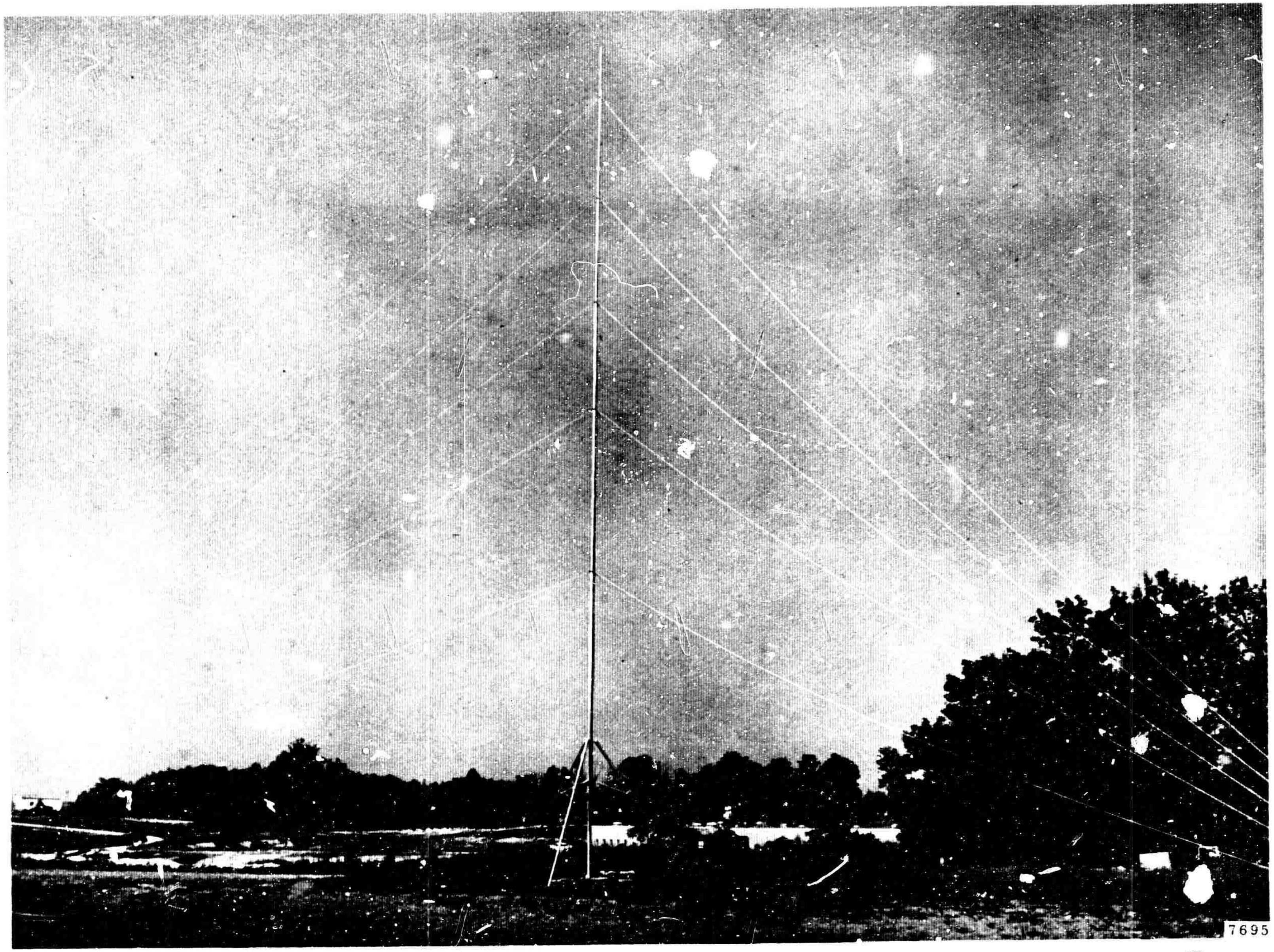

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Figure 5.3 Antenna Mast, with Launching Tripod and Guys, for Tests below 550 Mc/s

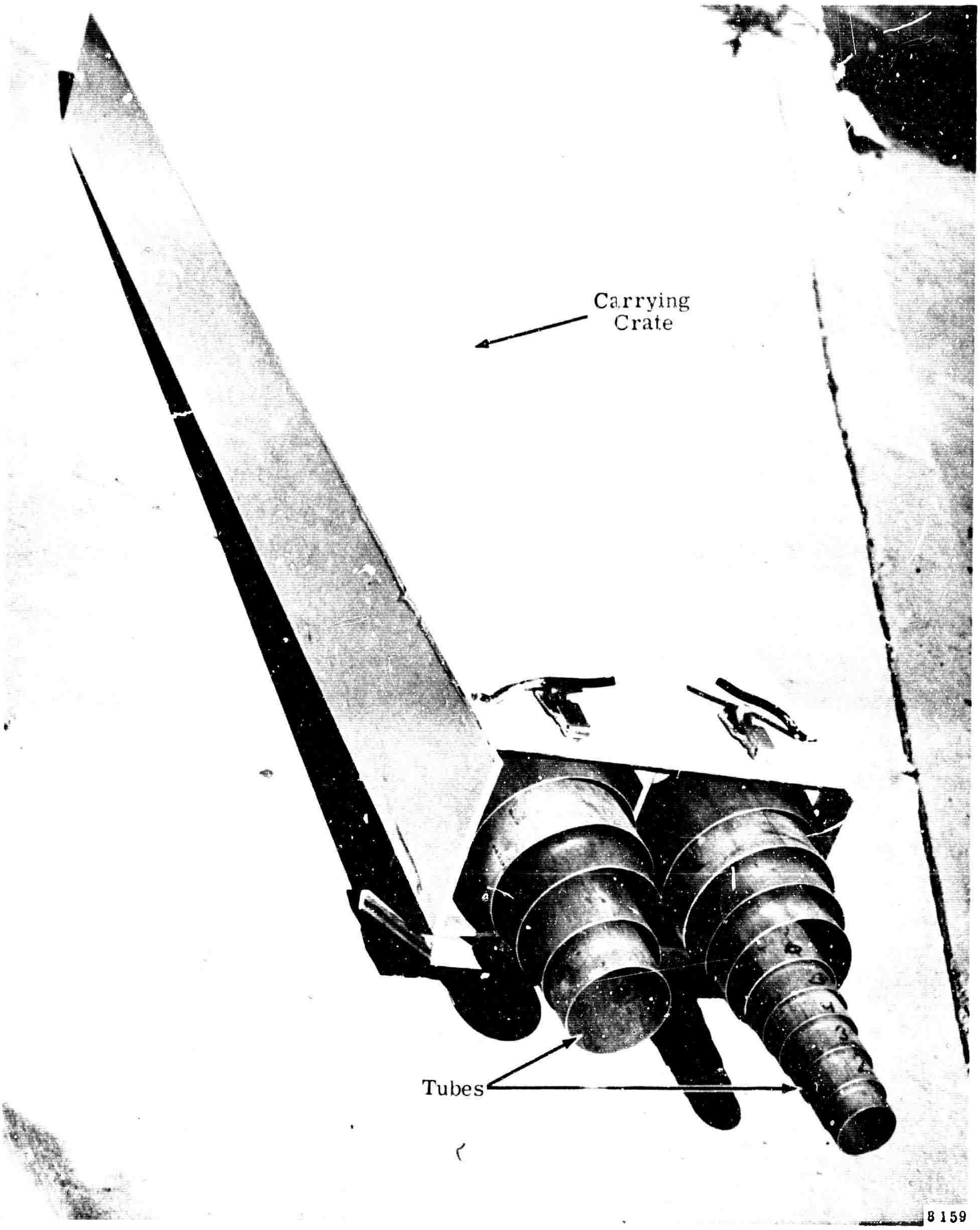

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Figure 5.4 Antenna Mast Tubes in Their Carrying Case

This process is repeated until the desired height is reached. The strength margin of the mast is great enough that it can be exten ied to 120 feet in the absence of winds.

5.5 Power and Impedance Measuring Equipment

The equipment used for the RF power and impedance measurements is the same as that used at Pak Chong. This equipment consists generally of RF ammeters, RF power meters and the associated directional and bi-directional couplers. RF ammeters with a range of up to approximately 25 Mc/s are used. The accuracy of the RF ammeters in this frequency range has been determined and is considered adequate, especially since the power level to be measured is quite high. Above 25 Mc/s, however, ammeters a·· unsatisfactory because of frequency limitations and lower power levels. Accordingly, power meters and directional couplers are used for measurements above 25 Mc/s. Typical equipments used for the RF power measurements above 25 Mc/s include the Sierra Model 164 bi-directional power monitor, used for measurements up to 400 Mc/s, the Hewlett-Packard Model 431B power meter with a Model 487A thermistor mount, for measurements from 10 Mc/s to 10 Gc/s, and miscellaneous Narda coaxial couplers for measurements from 250 Mc/s to 10 Gc/s. Various other types of power monitors are used to monitor power at elevated antennas and to provide remote readings at the ground or transmitter.

Measurements of antenna and transmission line parameters are made with commercially available equipment. Impedance measurements are required below 550 Mc/s to permit adjustment of test antennas and to determine their radiation characteristics. Although antennas are not generally adjustable above this frequency, it is important to check impedance to assure proper operation and calibration.

The following impedance measuring equipment is being used: General Radio Type 1606-A radio frequency bridge, General Radio Type 1602-B UHF admittance meter, and the Hewlett-Packard Type 806-B coaxial slotted section with the 809B universal probe carriage and the 442B probe.

5.6 Data Recorders

Continuous strip chart recorders, carried in vehicles, were widely used at Pak Chong to measure path loss variations. The complexity both of recording this data and later analyzing it, coupled to the desirability of using hand carried equipment for most of the Songkhla tests has restricted the continuous recorder to only a limited number of tests at Songkhla. Path loss variations, as explained in Section 3.2.2, will be determined through spot readings of maximum, minimum, and random values of field strength in a small sector. This procedure requires less equipment and produces results easier to analyze than do methods using continuous recorders.

However, to obtain a few, selected samples of the detailed variations in field strength as a function of time and distance, there will be some special tests using continuous recorders. The Varian Model G-11A recorders proved to be entirely satisfactory at Pak Chong, and they will be used in Songkhla for the above purpose.

5.7 Calibration Equipment

The fundamental procedure for calibrating field operating equipment is to maintain certain basic equipments which are to be used only in the calibration of the operating equipment. The operating equipment is checked against these calibration units at regular intervals. This procedure, used at Pak Chong, is continued at Songkhla. Equipment used as standards includes standard antennas, precision Weinschel attenuators, a Hewlett-Packard 434 Calorimetric Power Meter which covers the frequency range from dc to 12.4 Gc/s, and a Hewlett-Packard 431B Power Meter.

6. LIST OF PERSONNEL

The following individuals have made significant contributions to the work accomplished during this report period.

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13. ABSTRACT This is Semiannual Report Number 8 on a research program involving studies of the propagation of radio waves in a tropically vegetated environment. It represents the first report of activities in an area located about 40 miles from the coastal town of Songkhla in southern Thailand. A primary objective of this work is to supplement and also provide a comparison with the results, described in previous reports, of the extensive experimental and theoretical program near Pak Chong, Thailand. Songkhla is classified as a rainy tropical region and is characterized as having a 50 per cent heavier rainfall and much denser and taller vegetation than Pak Chong, which is classified as a wet-dry tropical region. Contained in the report are descriptions of the environment in the test area and of the test facilities that have been established. The experimental goals and test procedures are set forth, covering such topics as the effects upon transmission loss of frequency, antenna heights, polarization, and transmission range. Some preliminary results of measurements, based on all the data obtained from Songkhla as of 31 December 1966, are given in the form of 15 plots of basic transmission loss as a function of distance for various frequencies, transmitting antenna heights, and paths. The receiving antennas are fixed at a height of 6 feet, and the polarization is horizontal. Much of the instrumentation used at Songkhla is the same as that used at Pak Chong. Several changes, however, were necessary and are described in this report.

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Propagation						
Techniques						
Tropical Environment						
SEA - Southeast Asia						
Thailand						
Path Loss						
Climatology - Rainfall, Temperature						
Antenna Height						
Transmission Distance						
Jungle						

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